

This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`





2'11.

PRINCIPLES

OF

CONSTRUCTION OF FIELD ARTILLERY CARRIAGES.

BY

CAPTAIN W. KEMMIS, R.A.

REPRINTED FROM

"PROCEEDINGS, ROYAL ARTILLERY INSTITUTION," No. 6, Vol. VIII.

WOOLWICH:

PRINTED AT THE ROYAL ARTILLERY INSTITUTION.

M.DCCC LXXIII.

23.6. d. 13 (1)

BODLEIAN LIBRARY
OXFORD

PRINCIPLES

OF

CONSTRUCTION OF FIELD ARTILLERY CARRIAGES.

BY

CAPTAIN W. KEMMIS, R.A.

In considering the construction of field artillery carriages, it will be well first to review those principles which, more or less, must be carried out in the building of all in common, and then to make a few remarks upon the particular requirements which govern the details of construction of the various descriptions of carriages.

Essential Qualities.

The following qualities may be looked upon as the *desiderata* in a field artillery carriage—viz., "mobility," that the carriage may be brought rapidly, and without difficulty, into any required position, or change of position; "stability," that in any movement the carriage may be required to make, even if the ground is tolerably uneven, it may not overturn; "strength," "durability," and "simplicity" are essential qualities, which require no comment; and lastly, "convenience of transport" must of necessity be desirable in a country like Great Britain, with numerous large and distant colonies.

The first and chief point, then, to be kept in view in the construction of all field artillery carriages, is "mobility;" for without possessing this quality in a very high degree, they would be comparatively worthless.

In the following remarks, the question of the advisability of employing a two or four-wheeled carriage will not be entered into, it being assumed that the nature and purpose of the load compel the latter; which is, further, the best for draught, though the less advantageous for wheeling. Also, in all cases, the mode of draught will be taken as shaft draught, being that adopted in the service, as placing the carriage more under control in manœuvring than pole draught, and as being more advantageous for the wheel horses.

1. *Mobility.*—The "mobility" of a carriage is influenced by several things—viz., by the "traction" (commonly termed the "draught"), or amount of power requisite to put it in motion, and keep it in motion;

by its capability of reversing; and by its power of passing obstacles. To render, therefore, a carriage mobile, "the draught must be as light as possible." This necessitates, in the first place, the load being a minimum—that is, the weight of the gun, or ammunition, &c., to be carried being given, the weight of the carriage a minimum—and in the second place, that the load be properly distributed over the axles.

Before passing on to the other points which affect the draught, it is to be noticed that the distribution of the load depends upon the relative diameters of the fore and hind wheels, and upon the fact that the traction of the fore carriage, taken by itself, is usually more difficult than that of the hind; because the fore wheels make, as it were, the tracks, and in so doing reduce the height of any obstacles for the hind. These considerations point to the reduction of the load upon the fore axle as compared with that on the hind; but, on the other hand, the fact must not be lost sight of, that if too much weight be thrown on the hind axle relatively to the fore, it will cause the hind wheels to sink too much in yielding ground, and thereby (though the decrease of weight on the fore axle tends, as before, to lighten it) to increase the draught on the whole.

Again, for lightness of draught, the axles must be of such length as to give the same track to both fore and hind wheels; in order that, as above, the fore may, in doing their own work, also assist the hind. The diameter of the wheels must also be a maximum, and that of the axletree a minimum. With regard to the former, the diameter of 5 ft. has been fixed upon as that most suitable for the field wheel.

Lastly, that the draught may be light, the point of the attachment of the traces must be the most favourable—that is, as regards height from the ground; it must be such as to give the most advantageous inclination to the traces. The point of attachment to the horse—viz., the collar—being fixed, experience has shown that this inclination should be about $6\frac{1}{2}^{\circ}$.

The carriage, to be mobile, must, in addition to being light in draught, be "capable of wheeling, or reversing, very short;" that is, not only must the carriage be of a minimum length, but the angle through which the fore carriage can sweep must be as large as possible – which latter mainly depends upon the diameter of the fore wheels, and details of construction of the body of the carriage.

The mobility of the carriage is influenced by what may be called its "power of passing obstacles," which point, so far as the wheels and inclination of the traces are concerned, may be considered as included under "lightness of draught;" but beyond this, is influenced by the mode of connection of the fore and hind carriage, which should be such as to admit of vertical motion of the fore carriage about the point of connection, so that the fore carriage may move in that direction independent, to some extent, of the hind carriage. The distance between the axles also slightly affects the power of the carriage to pass obstacles, but need hardly be taken into account, as the length between the axles best suited for passing certain obstacles will not be the best for passing others. And here it may be as well to remark, with regard to the distance between the axles, that it does not in

ordinary cases affect the traction, providing that the relative position of the centre of gravity of the load as to the axles remains unaltered.

2. *Stability.*—"Mobility" in a field artillery carriage would not, so to speak, be perfect, unless accompanied by "stability," which point has, therefore, next to be considered. Stability is influenced by the number of points on which the carriage rests, and by the vertical and horizontal position of the centre of gravity with regard to those points. The carriage being supposed on the level, the first mentioned distance should be as small as possible, and the second as great as possible (which latter, with convenience of width, governs the track), to yield maximum stability. This will be readily understood by supposing a carriage placed upon the level, and a vertical drawn through the centre of gravity, then the carriage tilted over through a certain angle; when it will be seen that the higher the position of the centre of gravity, the greater the distance through which it has moved, and therefore the more nearly will the vertical then drawn through it be to falling outside the bearings on the ground. Again, with regard to the horizontal position of the centre of gravity from the bearing points, it is evident that the further it is from them, the greater moment the weight, acting at that centre, has to resist any force tending to overturn the carriage.

Stability in wheeling or reversing, will further be influenced (setting aside the weight of the carriage, already fixed at a minimum by the consideration of mobility) by the height and mode of connection of the fore and hind carriages, as well as by the height of the attachment of the traces to the fore carriage.

That the carriage may be stable in any position of rest or of motion to the front, it is simply necessary that the vertical through the centre of gravity should fall within the figure formed by joining with straight lines the points upon which it rests. In field artillery carriages, the stability is considered sufficient when the upsetting angle for the carriage, packed, is about 35°; that is to say, the vertical falls outside the points on which the wheels rest, and the carriage overturns, when it stands upon a side incline exceeding 35°.

3. *Strength and Durability.*—The next points to be taken into consideration in the building of the carriage, are "strength" and "durability." The material used should be the strongest consistent with lightness; the scantling of each particular part being, in the same view, at a minimum consistent with the stress which the part may be called upon to bear. The material should also be such as will stand well the effect of shot striking it, the action of climate, &c., and should not be liable to deteriorate when kept in store.

Of late years, wrought-iron has very much superseded wood as a material for carriages, being much more durable. For instance, a shot striking a bracket of an iron gun-carriage will make a clean hole through it, without splintering and damaging the adjacent parts; whereas a shot striking the bracket or trail of a wooden gun-carriage will splinter it, more or less. Notwithstanding, comparing iron with English oak, it is but slightly heavier for the same strength; because, from its nature, its mass can be better disposed to withstand any given

stress. Wrought-iron, however, is not so elastic as wood, and therefore will not absorb so much of any stress as the latter; and, again, has the defect of readily suffering deformation, and thus loss of strength through loss of form. This latter defect sometimes necessitates the scantling of the iron being made of greater dimensions than mere strength to resist a particular stress would require.

4. *Simplicity.*—"Simplicity" of construction in the carriage is the next quality to be kept in view; that is to say, as far as possible, there should be nothing complicated nor likely to get out of order; neither should any part be such that, if damaged, it could not readily be repaired. Again, looking at the carriages in the aggregate, the parts and fittings should, as far as possible, be interchangeable.

5. *Transport.*—"Convenience of transport" is a point which must not be lost sight of in building the carriage; in view of which, it should admit of being readily taken to pieces and conveniently stowed on board ship.

6. *Length.*—Lastly, the total length of the carriage should be at a minimum; not only, as mentioned before, for mobility, but that in column of route it may cover as little ground as possible.

A few further remarks may now be made upon the particular requirements of the gun-carriage, &c.

The Gun-Carriage, with Limber.

The present form of gun-carriage has been arrived at, as fulfilling the foregoing conditions, and also as convenient for bringing the gun into, and serving it when in, action; as furnishing a stable carriage for the gun in action; as allowing of a supply of ammunition and stores being carried with the gun, readily accessible for use; and as admitting of a proportion of men being carried upon the carriage in addition to its proper load.

With regard to the mobility of the gun-carriage, it is to be remarked that it has an advantage not possessed by ordinary carriages—viz., of having fore wheels of equal diameter to the hind, yet locking through a considerable angle. Further, the connection of the fore and hind carriage may be said to be perfect, as regards passing obstacles; for the vertical as well as the horizontal motion of the former is very independent of the latter.

In point of strength and durability, not only has the gun-carriage to be able to withstand the strains to which it may be exposed as a travelling carriage, but it also must have sufficient strength to withstand the action of the gun when fired at the most hurtful elevation.

In investigating the effect of the discharge of the gun upon the carriage, we may consider that discharge as simply producing a force or blow applied at the bottom of the bore, and acting in the line of the axis of the gun—though it is questionable whether the action is actually so simple. The gun—that is, its weight, charge, &c.—are supposed in the following remarks to be given and constant; and, unless the contrary

is specified, the carriage standing on the level, and the gun laid at any angle of elevation or depression. From the symmetry of the gun and carriage with regard to the vertical plane through their longitudinal axes,* we can further take the whole of the forces to be spoken of as acting in that plane. Taking, then, the single force applied at the bottom of the bore, we may conceive it resolved into two components—one horizontal, the other vertical. Now, a proportion only of this single force, or its components, is transmitted from the gun to the carriage; part—depending in amount upon the weight and thickness of metal of the gun—being expended upon the former.

Again, of the proportion transmitted to the carriage, the whole is not expended upon the carriage, but a small part transmitted to, and expended upon, the ground—the amount depending upon the nature of the latter. Now, the gun is supported upon, or attached to, the carriage at two points—viz., the trunnion holes, and the bearing of the elevating screw on the trail; but the attachment is not rigid, for the gun is moveable about the axis of its trunnions, and is hinged to the elevating screw, the latter being also moveable in a vertical plane round its bearing on the trail.

Taking, therefore, a certain horizontal and vertical force as transmitted from the gun to the carriage, we see, from the nature of the connection between the two latter, that the horizontal component will be applied at the trunnion holes, and the vertical component partly at the trunnion holes and partly at the bearing of the elevating screw—mainly, however, at the latter. The horizontal component decreases as the angle of elevation or depression with the horizontal at which the gun is fired increases. It exerts itself upon the carriage in two ways—viz., in giving it a motion of translation to the rear, and a twist or tendency to constrained motion about the point of the trail, as that point may be regarded for the instant as fixed. Hence, to render the effect of this component as little hurtful to the carriage as may be, the latter should in itself oppose the motion of translation as little as possible; which amounts to saying that its inertia, and consequently its weight, should be a minimum (the latter we have already seen mobility also demands); while to reduce the twisting strain to a minimum, the trunnion holes should be as low as other considerations will admit. The vertical component will act in an upward or downward direction, according as the gun is fired at an angle of depression or elevation with the horizontal, and will increase with the angle. If upward, it will tend to tear the carriage asunder; if downward, to crush it—the latter being that which tells most upon the carriage, on account of the resistance of the ground upon which the carriage bears. The body of the carriage is supported upon the ground at two points—viz., the axletree arms and the point of the trail; when, therefore, the blow of discharge is transmitted to the carriage, if the vertical component act downward, we shall have at these points certain resistances called into play, that at the arms being

* It is not only convenient, but necessary that these axes should lie in the same vertical plane, to prevent the carriage receiving a twist horizontally.

much greater than at the point of the trail; because the axis of the trunnion holes lies vertically to the front of the axis of the axletree, and also the bearing of the elevating screw is nearer the axletree than to the point of the trail—in fact, because the vertical component, part of which acts at the trunnion holes and part at the bearing of the elevating screw, acts as a whole at some point intermediate between the two.

Again, this being the position of the point of application, as it were, of the total vertical component, it is evident that the trail and brackets (as part of the trail) have to support the whole brunt of it, while the axletree has only to bear a part of that whole. If the vertical component act upwards, the resistances of the ground will not then be called into play, but the weight of the carriage acting downward at its centre of gravity will offer the resistance; the tendency being, as before said, to tear the carriage asunder. When the vertical component acts downwards, and the resistances of the ground are called into play, they will in general be less in total amount than the component itself, the excess of the latter being expended upon the ground. This excess will vary with the hardness of the ground, and the carriage will be saved according as the latter is more or less yielding. Just in the same manner, the ground, by its nature, will influence the recoil, and, as before mentioned, in so doing influence the amount of the horizontal component spent upon the carriage, and the portion transmitted to and expended upon the ground.

In a similar manner, the slope of the ground to the front or rear, by influencing the recoil, affects the destructive effect upon the carriage.

It only remains to be noticed, with regard to the force transmitted from the gun to the carriage, that in guns having the axis of the trunnions below the axis of the piece, other things equal, the blow upon the trail at the bearing of the elevating screw is more severe than in guns in which the axes intersect; because the impulse on the bottom of the bore, acting in the line of the axis, has a moment or twist round the axis of the trunnions.

Carriages having a detached elevating screw are liable to a second and destructive blow upon the trail, from the breech of the gun and the screw falling back to their place, after the rebound of the trail from the ground has thrown them up.

As regards serving the gun in action, it is to be observed that the carriage is admirably adapted for laying the gun; admitting of ready motion being given to the latter in a plane perpendicular to the axis of the trunnions and to the carriage itself, and therefore to the gun in a plane at right angles to the former.

As to furnishing a stable carriage for the gun in action, the form adopted gives three points of support, the vertical through the centre of gravity falling between them, and hence a stable carriage. Not only so, but a carriage that is stable when the gun is fired; as the axis of the gun lies in the vertical plane (the wheels being on the level) containing the centre of gravity of the system, while the rear point of support of the carriage is in the same plane, and at a sufficient distance from the centre of gravity.

It now remains to make a few remarks upon the parts of the gun-carriage in detail.

The wheels and axletree are of sufficient importance to be treated of by themselves, and it need only here be mentioned, with regard to the destructive action of the gun upon the carriage, and axletree in particular, that, looking at their inertia, the weight of the wheels should be a minimum (as well as for mobility).

The scantling of the parts has been arrived at from experience and experiment, as well as from scientific considerations; being always kept at a minimum consistent with proper strength, for the sake of mobility, which consideration in the following remarks is understood to be kept in view.

The wooden axletree bed, hitherto used, served as a convenient means of securing the axletree to the carriage body, more particularly in wooden gun-carriages; it also distributed the load in travelling, and the strain in firing, more uniformly over the axletree, serving by this means, and by its own additional strength, to admit of the axletree being made lighter than it otherwise could be.

In iron carriages, however, it gives no additional facility of construction, and though it has the advantage of assisting the axletree to some extent, it is a questionable advantage; so that in this case it would appear to be a superfluous, and it may even be said to be a faulty form of construction—a compound axletree, as it were, being made of two substances differing so much in elasticity as wood and iron, and further, the material having the greatest elasticity placed to receive the pressure or blow; in fact, the iron may be broken before the full strength of the wood has been called into play. For this reason, it is probable that in iron carriages of the future it will be dispensed with, and the axletree modified.

In form, the bed is of the same section throughout, but not rectangular; because while the upper surface is parallel to, and the sides perpendicular to, the under surfaces of the brackets into which it is housed, its under surface must be such as to be parallel to the ground when the trail is upon the limber-hook, in order that the lower surface of the axletree may be parallel to the same—that being the position of the axletree for which the lead and hollow are calculated.

The dimensions of the bed depend entirely upon the axletree; its length—in which direction the fibre should run—being the same as that of the body of the axletree; its depth being regulated by the height considered necessary to be given to the axis of the gun (which is governed by the general rule that the gun should be able to fire over a parapet 3 ft. 6 ins. high at 5° depression); and its width such that it may be able to retain a good hold upon the axletree without giving way itself.

The height of the brackets must be at a minimum consistent with the maximum elevation and depression necessary for the gun—viz., about 15° elevation, or 10° depression, being given when required—and also to give (in wooden gun-carriages) room for sufficient depth of housing over the axletree bed.

The depth must be kept, as stated, at a minimum, because the deeper the brackets, the stronger, and therefore heavier, they must be

in themselves; and again, because the higher they are, the less will be the stability of the system.

The thickness of the bracket should be at a minimum consistent with strength. Its length must be such as to afford secure attachment to the trail in wooden carriages; in iron carriages, the brackets and trail are in one.

With regard to the position of the trunnion holes in the brackets, it is ruled by the consideration that it must not be so far back as to make the weight on the limber hook—the position of which is, in a measure, fixed by other things—excessive, but such as easiness of lift in unlimbering demands; and, so far as it may be taken into account, of correct distribution of the load on the fore and hind axles. At the same time, the position of the trunnions must not be so far forward as that when the carriage is unlimbered and gun fired, the trail would rebound from the ground, and the system turn over to the front. Neither should the weight on the limber-hook be so little as in travelling over rough ground, or up an incline, to cause a succession of heavy blows by the trail against the key securing it. In practice, in gun-carriages for the lighter field guns, the axis of the trunnions—the gun being unlimbered and on the level—and the axis of the axletree of the carriage are very nearly in the same vertical plane; which with the construction of the trail, &c., causes the point of the trail to press upon the ground with a force equal to about half its own weight.

In the carriages for the heavier guns, it is found impossible to combine the required conditions in one set of trunnion holes, and it becomes necessary to have one set for the gun in travelling, and another in firing.

The dimensions of the trail are fixed as follows:—Its length chiefly depends upon the influence it has upon the recoil when the gun is fired, and therefore upon the extent to which it is considered desirable to check that recoil; bearing in mind, as before mentioned, that the more the recoil is checked, the greater will be the destructive effect upon the carriage. In this view, experience has shown that the angle which the trail makes with the ground should not exceed 22°. Setting this point aside, the length of the trail must be sufficient to prevent any danger of the gun and carriage turning over to the rear about its point on firing. Minor considerations which affect the length of the trail are, that it must be long enough to admit of easy access between the fore and hind wheels, and not so long as to make the fore and hind axles unnecessarily far apart. As we have seen, it is where the elevating screw is supported that the greatest breaking strain comes upon the trail, and where, therefore, its cross section must be the greatest; depending not only upon the amount of the blow communicated through the elevating screw—which is exceedingly difficult to calculate—but also upon the distance from the elevating screw to the point of the trail. Towards the point of the trail, though the cross section may be decreased with reference to the blow on the elevating screw, it must be such as to be able to withstand any lateral strain the trail may be liable to be exposed to; for instance, the jamming of the fore wheel against it in locking, and also any twisting strain in going over rough ground.

The limber is fitted to carry the supply of ammunition which accompanies the gun. Three points about it deserve notice—viz., its load, the position of the limber-hook, and the point of attachment of the traces.

The load on the fore axle, as before mentioned, should be less than that upon the hind axle; but the amount of difference on the gun-carriage must of necessity be more or less modified by the quantity of ammunition which is considered absolutely necessary to be carried with the gun.

The position of the centre of gravity of the load must always be such that the vertical through it will fall in front of the axletree, that there may be no tendency to rotation to the rear; otherwise, the position of the load must be such that when combined with the effect of the distribution of the remainder of the whole load, it will throw a sufficient amount of weight, and no more, upon the shaft horse's back. The ammunition being carried in boxes facilitates stowing on board ship, &c.

The height of the limber-hook from the ground is fixed by convenience of lifting the trail, for unlimbering and limbering-up; its position between the axles, by the length given to the trail, the proportion of the total load to be thrown upon each axletree, and, as far as possible, solidity of attachment to the body of the limber.

The considerations governing the point of attachment of the traces have been mentioned before, under the head of lightness of draught, in respect of mobility.

The Ammunition Wagon.

The wagon must be able to accompany the gun over any ground the latter may have to pass, therefore the general principles of mobility, &c., apply equally to it; and the present form of ammunition wagon has been arrived at as best carrying out these principles, and the particular purpose for which it is intended; the parts, so far as possible, being interchangeable with those of the gun-carriage.

With regard to the distribution of the load upon the axletrees, the arrangement of the ammunition in boxes admits of the approved proportion—viz. 1 : 2—being more conveniently and more nearly approached than in the gun-carriage.

Nothing requires to be said upon the parts of the wagon in detail. What has been said about the parts of the gun-carriage, viewing it as a travelling carriage, applies to it; the perch in the one, corresponding to the trail in the other.

The Remaining Artillery Carriages.

These carriages are not intended to come under fire in the same manner as the gun-carriage, or even as the ammunition wagon; yet, since they must always be within reach of the battery to which they belong, and therefore to some extent conform to its movements, the general principles of construction require to be carried out in them—at least such has been the view held hitherto, as is well expressed in

Migout and Bergery upon the theory of gun-carriages—viz., "that these wagons have not to follow all the movements of the troops, like the gun-carriages and ammunition wagons, nevertheless they require great mobility; for, having constantly to keep in the neighbourhood of the batteries, they take a part in the principal changes of position. It is even necessary, in certain cases, that they should be able to rejoin the other carriages, notwithstanding the difficulties of the ground. These considerations lead us to construct these wagons on the plan of the gun-carriage and ammunition wagon."

This view has, however, of late been modified—namely, in the substitution of a general service wagon for the old limber wagons, as simplifying the field equipment by reducing the number of different descriptions of wagons, and as being more convenient for transport of *matériel*.

The minor details of construction of the old limber wagons were governed entirely by the particular purpose for which each was intended. In all, the parts were, as far as possible, interchangeable; not only among themselves, but also, when practicable, with the parts of the gun-carriage and ammunition wagon, for the sake of simplicity of equipment.

As to the new general service wagon for the artillery, the principles of construction of that particular form of wagon belong more properly to the principles of construction of wagons for the transport service.

ROYAL ARSENAL,
July 1, 1873.

PRINCIPLES

OF

CONSTRUCTION OF TRANSPORT CARRIAGES.

BY

CAPTAIN W. KEMMIS, R.A.

REPRINTED FROM

"PROCEEDINGS, ROYAL ARTILLERY INSTITUTION," No. 6, Vol. VIII.

WOOLWICH:

PRINTED AT THE ROYAL ARTILLERY INSTITUTION.

M.DCCC.LXXIII.

2316 d. 13



REVIEW

OF

CONSTRUCTION OF TRAN[illegible]

BY

CAPTAIN W. [illegible]

Field
in a

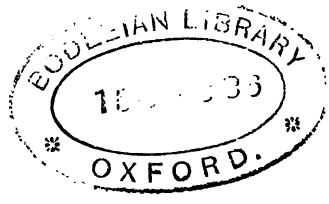
such
ıor to
their
regard

"PROCEEDINGS, ROYAL [illegible]

subject
emarks
ved, and
lect the

a wagon
a
d




BODLEIAN LIBRARY
OXFORD.

PRINCIPLES

OF

CONSTRUCTION OF TRANSPORT CARRIAGES.

BY

CAPTAIN W. KEMMIS, R.A.

Remarks.

What has been said in a former paper on the Construction of Field Artillery Carriages, viewing them as travelling carriages, is, in a modified form, applicable to transport carriages.

These carriages are not required, in general, to move over such broken ground as artillery carriages may have to surmount, nor to move at such rapid pace. Hence—and bearing in mind also their special purpose, namely, the conveyance of stores—we may regard their essential qualities as the following:—

Essential Qualities.

Capacity to receive, and strength to convey, their load.
Stability in carrying it.
Lightness of draught, and moderate mobility.
Durability, simplicity, and facility of shipment.

Before discussing these qualities in detail, it will simplify the subject to assume that the vehicles to be employed are wagons* (a few remarks upon carts being afterwards made); that the load to be conveyed, and team to draw it, are fixed; and also, for the time, to neglect the question of springs.

Capacity and Strength.

As to capacity for load—the first mentioned requisite—a wagon should be able to receive the weight it is designed to carry in a reasonably bulky form, without it being necessary to pack the load

* Wagons not limbered; because it is undesirable to leave space between the axles of no use for loading, as in a limbered wagon.

very high—which is inconvenient, and otherwise objectionable. In point of strength, the wagon should, as regards the material of which it is constructed, and the scantling of the various parts, be able to support with safety its given load, and to take it without breaking down over a bad as well as a good road, or even across a small ditch, or other obstacle.

Now, the form of the fore carriage, and the manner of its connection with the hind carriage or body, influences to a very considerable degree the capability of the wagon to pass obstacles without hurt. For example: the fore carriage first meets any obstacle or rut to be passed, and in crossing it, rises and falls or falls and rises, while the hind carriage is still on the original level. This action necessarily throws a strain upon the connecting arrangement of the fore and hind carriages, as well as upon their surfaces of contact, to be repeated when the hind wheels arrive at the same obstacle. In most wagons, the connection between the fore and hind carriages is by a long vertical main pin; and the surfaces of contact, wheel plates or otherwise, are at some distance around or in front and rear of the point of connection. This being the case, it is evident that the strain in question will be less in proportion as the distance from the main pin or point of connection to the surface of contact is decreased, and also as the play of the pin is increased. (The strain upon the pin itself will, of course, increase with the amount of play allowed to the pin). Thus, the more nearly the bearing surfaces of the fore and hind carriages approach to unite in one point—as they do in a limbered wagon—and the more play there is at the point of connection—as in the description of wagon just named—the more strong will the wagon be for passing broken ground.

To reducing the bearing surfaces in an ordinary wagon—*i.e.*, one without limber—to one point, there are, however, objections; namely, that so doing decreases the stability, and under certain circumstances admits of the likelihood of the wagon body being much strained.

Stability.

The next essential quality in a wagon is stability; that is to say, a wagon should not overturn when tilted sideways through a considerable angle. As has just been stated, having the hind carriage bearing upon the fore carriage at only one point decreases the stability; because then the base formed by joining the bearing points of the body is a triangle outside of which the vertical through the centre of gravity will soon fall, supposing the carriage to be gradually tilted over; and of course, as soon as this happens, the wagon upsets.

We have, however, already seen that one bearing point between the fore and hind carriage makes a wagon much better adapted for going over rough ground. From this, and what has just been said about stability on three bearing points, it would appear that great stability, and at the same time perfect construction as regards strength, are incompatible, but that one quality must be more or less sacrificed to the other, unless the wagon be made of the form of a limbered wagon, similar to a field gun-carriage or gun ammunition wagon.

Mobility.

With regard to the third requisite in a wagon, the conditions which influence the draught have already been sufficiently dwelt upon when speaking of artillery carriages. The height of the hind wheel of transport wagons varies usually from 4 ft. 2 in. to 5 ft. The greater it is, the more advantageous for draught; but a high wheel carries with it the evil of increasing the height of the bottom of the wagon for loading, and diminishing the stability. The height of the fore wheel should be also as great as possible, for ease of draught. In most wagons, the height of the hind wheel being determined, that of the fore wheel is made a maximum consistent with locking under, so that the wagon may be able to reverse in a short space; in some wagons, however, the latter is sacrificed, and the fore wheel made of equal diameter to the hind.

Durability, &c.

The remaining essential qualities of a wagon need no comment.

Carts.

Carts are used for transport as supplementary to wagons; for they furnish convenient means of moving small loads. They could not entirely take the place of wagons, for their capacity is not sufficient; and even if made capacious enough, so many more carts than wagons would be required, that columns of route would be too long. Carts have, however, another and more serious defect—viz., that of being much more fatiguing to the shaft horse, not only from the amount of weight which must necessarily be thrown upon him, but from the jolts or shocks which, more or less, are communicated to him as the cart passes over rough ground. The position of the centre of gravity of the cart (and load) is the only point which needs particular notice in the construction. It should always lie to the front of the axis of the axletree, and only so far so as to throw a moderate weight upon the shaft horse. It might, at first sight, be supposed that it would be better to balance the cart exactly on its axletree, and not have any pressure upon the shaft horse when the cart is at rest. If, however, this was done, it would be found that the inequalities of even a tolerably good road would produce such jolts that the horse would be more fatigued than with a constant moderate pressure upon his back.

Springs.

The advantages obtained by the addition of springs to a wagon or cart, are "lightening of the draught," and "saving to the carriage and load in passing over rough ground." In order that a wagon or cart without springs may surmount each successive obstacle of a rough road, both it, and as a consequence its load, have to be raised to the height of the particular obstacle as the wheels pass it. Suppose, now, the same wagon

or cart to be fitted with springs. The body, with its load, will not have to be raised to the height of each obstacle; for, as the wheels surmount it, the springs will yield to some extent, consequent upon their pliancy and the *vis inertia* of the weight above them. In this manner it arrives that much less exertion is required to make a wagon with springs pass over an obstacle of given height, than to make the same wagon without springs pass it. In other words, the draught of the spring wagon is the easier. Springs have also the advantage of saving the wagon and its load. They do this by lessening the shocks due to the badness of the road, acting not only by reducing the height due to an obstacle through which the body must rise and fall, but also by rendering the blow less severe; in fact, they convert what would otherwise be a blow into a pressure.

On the fore carriage of a wagon, springs are particularly useful; as they allow of some yield when, by reason of the unevenness of the ground, extra pressure is thrown upon any part in particular of the bearing surfaces.

Two comparatively slight disadvantages accompany the use of springs. One is, that the body is not so perfectly rigid over its axles as if without springs—some slight lateral motion of the body and load above the axles being a necessary consequence of the nature of the connections; the other is, that the use of springs necessitates the bottom of the wagon being rather higher than it otherwise need be. Both these points affect the stability, and the latter also convenience of loading.

It may also be urged that the addition of springs renders the construction of a cart or wagon more complicated and delicate. No doubt, to some extent, this is the case; but the springs used in the service—viz., the semi-elliptical—are simple in construction and easily repaired.

Springs on a wagon or cart should be of such strength that, with the full load and the wagon at rest, they should not yield more than half the distance (measured along the radius of the spring at the centre, or over the point of attachment) through which they would have to bend to become straight.

The strength of a steel spring is proportional to the number of leaves and to the width and thickness of each leaf, while it is inversely proportional to the span. Founded, no doubt, upon this, and upon the results of experiments, the following formulæ, which give very good approximations to the truth, were given in the "Engineer" of January 12, 1872:—

Let s = span or length in inches of a spring,
b = breadth in inches of a leaf,
t = thickness in sixteenths of an inch of a leaf,
n = number of leaves,
c = a constant,

then, the working strength of the spring in tons $= \frac{b \times t^2 \times n}{s \times c}$, where $c = 11{\cdot}3$; and the elasticity or deflection per ton of load $= \frac{s^3 \times c}{b \times t^3 \times n}$, where $c = {\cdot}105$.

In the transport heavy spring wagon (made by contract), which has second class wheels and axles and takes a load of 2 tons, in a hind spring we have

$$s = 43\tfrac{1}{2}''$$
$$b = 2\tfrac{1}{4}''$$
$$t = \tfrac{1}{4}''$$
$$n = 10$$

Therefore the working strength of the spring $= \dfrac{\frac{9''}{4} \times (4)^2 \times 10}{43\frac{1}{2}'' \times 11{\cdot}3}$ $= {\cdot}73$ ton, or $\frac{2}{3}\frac{3}{0}\frac{2}{0}$ ton; while, supposing the distribution of the load over the axles to be in the proportion of 1 on the fore axle to 2 on the hind, the actual load upon the spring $= \frac{1}{2}$ of $1\frac{1}{3}$ tons $= \frac{2}{3}$ ton, or $\frac{6}{9}\frac{6}{0}\frac{6}{0}$ ton.

Also, for the same spring, the deflection per ton of load $= \dfrac{\left(\frac{87}{2}\right)^3 \times {\cdot}105}{\frac{9}{4} \times (4)^3 \times 10}$ $= 6''{\cdot}002$; or for the actual load of $\frac{2}{3}$ ton upon the spring $= \frac{2}{3} \times 6{\cdot}002$ $= 4''{\cdot}001$, which exceeds by $0''{\cdot}626$ half the amount of deflection required to bring the spring straight—which latter, as already mentioned, ought not to be exceeded.

THE

ACTION OF DISCHARGE UPON A FIELD GUN-CARRIAGE,

AS ILLUSTRATED BY

THE 16-PR. M.L.R. GUN OF 12 CWT.

BY

CAPTAIN W. KEMMIS, R.A.

WOOLWICH:
PRINTED AT THE ROYAL ARTILLERY INSTITUTION.
M.DCCC.LXXIV.

2316. d. 13 (3)

BODLEIAN LIBRARY
7L 33
OXFORD.

THE

ACTION OF DISCHARGE UPON A FIELD GUN-CARRIAGE,

AS ILLUSTRATED BY

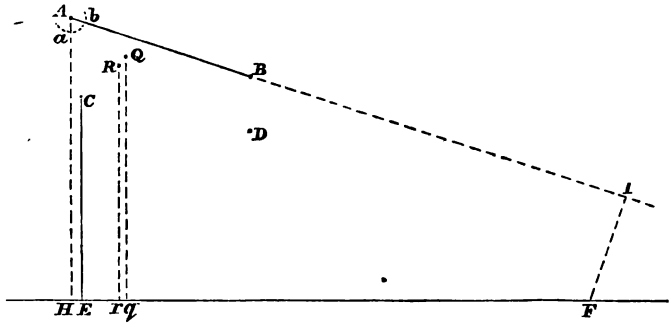
THE 16-PR. M.L.R. GUN OF 12 CWT.

BY

CAPTAIN W. KEMMIS, R.A.

If a 16-pr. gun-carriage of the latest construction be unlimbered upon level ground, and the length of the body of the axle (49″·5) be taken as the distance between the wheels, or supporting points, the statical breaking weight of the box-girder axletree-bed, applied in a vertical direction midway between the supports, will be found, by calculation in the usual way, to be 23·22 tons.

Assuming 30° (which there is no doubt is under the mark) to be the elevation at which the gun is fired when the limit of 23·22 tons vertical pressure upon the axletree and bed is reached, a few deductions as to the statical strains upon the carriage may be made. In doing so, for sake of simplicity, the forces called into action upon discharge will be taken as acting in one plane—namely, the vertical plane through the longitudinal axis of the gun; in fact, any strain due to the twist of the rifling, being comparatively small,* will be neglected.



* In severe trials, this strain makes itself evident by the right capsquare giving way, and also the right socket supporting the elevating-screw box.

In the figure, AB represents the line of the axis of the bore (making an angle of 18° with the horizontal), A being its intersection with the axis of the trunnions, and B with the axis of the bolt attaching the elevating-screw; C represents the axis of the axletree-arms at the shoulders, D that of the trunnions at the elevating-screw box, E and F the bearings of the carriage upon the ground—*i.e.*, respectively of the wheels and trail.

Let P = the maximum pressure exerted on discharge upon the carriage, applied to it at A,* and acting in the direction of the axis of the gun,

P^Y = the vertical component of P,

P^X = the horizontal component of P,

R = the maximum vertical resistance of the axle and its bed, = 23·22 tons,

W = the weight of the gun and carriage (without wheels), acting at their common centre of gravity Q, = 20 cwt.,

W' = the weight of the gun and carriage (with wheels), acting at their common centre of gravity R, = 24 cwt. 1 qr. 24 lbs.

Then, AH, CE, Rr, Qq,† being drawn perpendicular to the ground line,

$$R \times EF = P^Y \times HF + W \times qF;$$

$$\therefore P^Y = \frac{R \times EF - W \times qF}{HF}$$

$$= \frac{23{\cdot}22 \times 77{\cdot}25 - 1{\cdot}0 \times 70{\cdot}85}{78{\cdot}75}$$

$$= 21{\cdot}87 \text{ tons},$$

$$\text{and } P = \frac{P^Y}{\sin 30°}$$

$$= \frac{21{\cdot}87}{{\cdot}5}$$

$$= 43{\cdot}74 \text{ tons};$$

or, per square inch of area of cross section of the bore,

$$\frac{43{\cdot}74}{10{\cdot}178} = 4{\cdot}297 \text{ tons.}$$

This being the maximum pressure transmitted to the carriage, if the maximum pressure exerted in the bore of the gun upon discharge be, as is said, 14 tons per square inch, there remains a balance between the two of 9·703 tons per square inch as the maximum force expended upon the metal of the gun. It may, however, be objected that 4·297

* The absolute point of application is at first at a—the lowest point of the trunnion bearing—from which it is immediately changed along the bearing towards b.

† These lines are respectively 43″·25, 31″·0, 36″·0, and 37″·1 in length.

and 14 tons are really rather the expressions of blows than of pressures proper, and therefore that they are not strictly comparable; from which it follows that the balance between them of 9·703 tons may not be quite just.

The greatest elevation permitted by the form of the carriage to the gun is 18°. When the gun is fired at this elevation, the effect of the force transmitted to the carriage ($P = 43{\cdot}74$ tons) will be as follows:—

$$\begin{aligned} P^Y &= P \times \sin 18^\circ \\ &= 43{\cdot}74 \times {\cdot}309 \\ &= 13{\cdot}515 \text{ tons}, \\ P^X &= P \times \cos 18^\circ \\ &= 43{\cdot}74 \times {\cdot}951 \\ &= 41{\cdot}596 \text{ tons}. \end{aligned}$$

Also, P has a moment with respect to the point $F = P \times FI$ $= 43{\cdot}74$ tons $\times$ $16''{\cdot}6$, which comes as a twist upon the bracket sides of the carriage, tending to bend them and tear them away from the second transom. This moment is opposite in direction to the moment, about the same point, of the weight of the carriage, with wheels and gun, acting at R, and $= W' \times rF = 1{\cdot}335$ tons $\times$ $72''{\cdot}05$. When, therefore, the first twist comes into play, it is opposed by the second, the resultant of both being a moment of 37·95 tons $\times$ $16''{\cdot}6$ that is acting in the same direction as P, and with the same arm. This resultant makes itself apparent on discharge by the "jump" of the gun, which in effect increases the elevation of the latter beyond that shewn by the tangent scale, and consequently affects the range of the projectile. To reduce the jump to a minimum, it is evident that in the construction of a carriage the main point is to keep the axis of the trunnions at as small a height from the ground as possible.

In addition to the small constant pressure upon the head of the elevating screw, from the centre of gravity of the gun being $0''{\cdot}15$ to the rear of the axis of the trunnions, there is a pressure upon it on discharge, due to the moment of the force P about the lower points of the trunnion-holes, upon which points the trunnions, having certain play in the holes, rested previous to the gun being fired. This moment equals 43·74 tons $\times$ $2''$, which, the screw being at a perpendicular distance of $28''$ from the bearing points, exerts a pressure upon it of 3·124 tons, which is transmitted to and expended upon the trail.

The statical breaking weight of the wooden bed first tried in the 16-pr. gun-carriage, under the same conditions as before, was 8·966 tons, and of the axletree used with it 4·164 tons, giving a total breaking weight for the bed and axle of 13·13 tons.

The gun and its charge not having been altered, the force P transmitted to this carriage was the same as to the latest pattern carriage—namely, 43·74 tons.

From these data (R and P) the angle of elevation at which the gun

is fired when the limiting value of R is reached and the axle and bed break, can be deduced, thus :—

$$R \times EF = P^Y \times HF + W \times qF,$$

$$\therefore P^Y = \frac{R \times EF - W \times qF}{HF}$$

$$= \frac{13{\cdot}13 \times 77{\cdot}5 - 1{\cdot}0076 \times 70{\cdot}4}{78{\cdot}75}*$$

$$= 11{\cdot}98 \text{ tons.}$$

$$\text{But } P = \frac{P^Y}{\text{sin of } \angle \text{ of elevation}},$$

$$\therefore \text{ sin of } \angle \text{ of elevation} = \frac{11{\cdot}98}{43{\cdot}74}$$

$$= {\cdot}27396;$$

$$\therefore \angle \text{ of elevation} = 15^\circ\ 54'.$$

Now, in carriages of this construction, as a fact, the axletree and bed would not stand the gun being fired at so high an elevation. To reduce, therefore, the calculated angle, either the value of P^Y—or, what is the same thing, of R—must be diminished, or that of P increased. The latter is inadmissible; for it would amount to saying that a carriage of the latest construction would not stand when the gun was fired at an elevation of 30°, which elevation, as before said, is really under the mark. It therefore remains that the value of P^Y—or rather of R, from which it is obtained—is too high; and this, no doubt, is the true case. In fact, it is not fair to take the total strength of the axletree and bed combined as the sum of their separate strength; for the elasticity of the wooden bed is greater than that of its iron axle, and consequently the latter is broken before the full strength of the former has come into play.

JUNE, 1874.

* The weight and distances vary slightly from those of the latest pattern carriage.

PRINCIPLES

OF

CONSTRUCTION OF WHEELS AND AXLETREES.

BY

CAPTAIN W. KEMMIS, R.A.

REPRINTED FROM

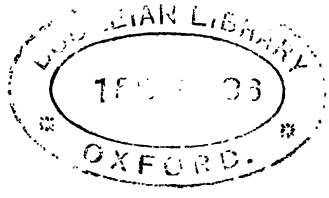
"PROCEEDINGS, ROYAL ARTILLERY INSTITUTION," No. 7, Vol. VIII.

WOOLWICH:

PRINTED AT THE ROYAL ARTILLERY INSTITUTION.

M.DCCC.LXXIV.

2316.d.13 (4)


OXFORD

PRINCIPLES

OF

CONSTRUCTION OF WHEELS AND AXLETREES.

BY

CAPTAIN W. KEMMIS, R.A.

The "object" of using wheels is to lessen the resistance to the movement of a carriage over the ground, by converting that resistance from one of "sliding" friction, or the friction of a surface of contact, to one of "rolling" friction, or the friction of a line of contact.

When wheels are used, rolling friction is developed not only between them and the carriage body—that is, between their pipe-boxes and the axletree-arms—but also between them and the ground; the first mentioned portion of the friction alone resists the movement of the carriage, the second prevents the wheel from sliding.

The wheel, in carrying out its object, attains, from its form, some minor advantages, thus:—Suppose, for simplicity, the carriage standing on the level, and power applied to move it at the axis of the axletree in a direction perpendicular to the latter and parallel to the ground; then, the friction between the pipe-box and axle, which tends to prevent the wheel turning, acts with a leverage equal to the radius of the pipe-box, while the power making the wheel to roll acts with a leverage equal to the radius of the wheel; thus the power has an advantage over the friction in the proportion of the radius of the wheel to that of the axle. Again, if the wheel meets a small obstacle in its path, the power, with regard to that obstacle, has a greater leverage, measured by the perpendicular let fall from the point of contact upon its direction, than the resistance of the weight, measured in a similar manner. This gain is true, as stated, with regard to small obstacles only; when the height of an obstacle exceeds a certain limit, it is manifest that the gain no longer holds good. If the obstacle, instead of being raised, be in the form of a transverse rut, the wheel gives a further advantage, proportional to its radius, in spanning the rut.

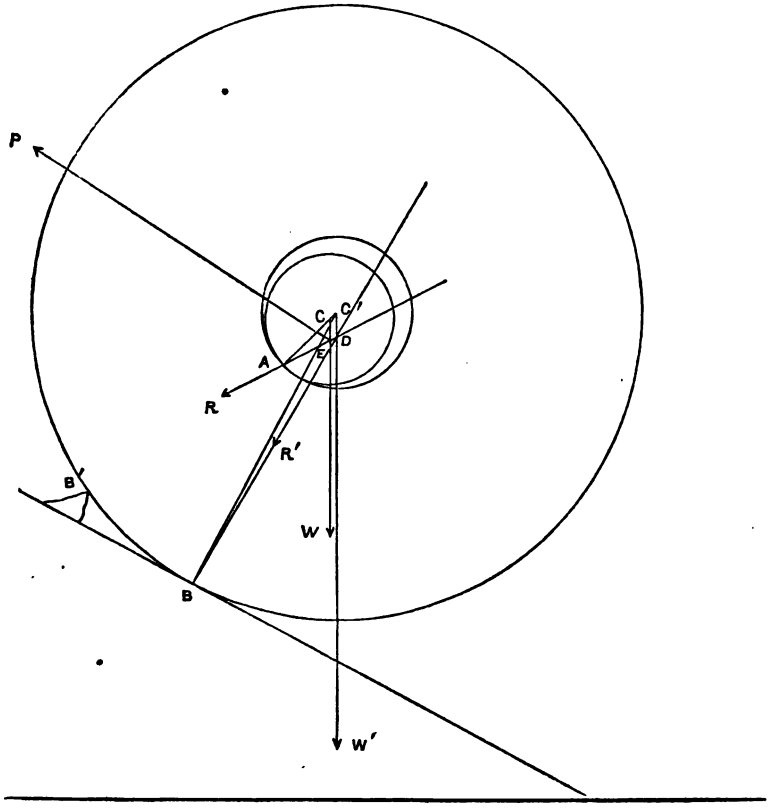
Setting aside special obstacles in a road to the motion of a wheel, certain what may be called imperfections exist in every road, which, as well as irregularity of form in the wheel itself, oppose some resistance to rolling. Such imperfections are: unevenness of surface, want of

perfect hardness, and want of perfect elasticity. The first defect causes obstacles to be presented to the wheel at each instant; the second—want of perfect hardness—causes the ground to yield, so that the wheel in its onward progress is continually opposed by the materials of the road immediately in its front. In the case of a perfectly elastic road, this would be of no consequence; for the compressed materials, as the wheel passed over them, would expand again just so much as compressed, and in so doing would react upon the wheel in rear with the same amount of force as expended by the wheel in compressing them.

The relations between the forces which act upon the wheel and axle are shown in Fig. 1, and may briefly be stated as follows:—

W = half weight of axle and load,
W' = weight of wheel,
P = traction or power, its direction making an angle β with the horizontal,
ϕ = limiting angle of resistance between the pipe-box and ~~wheel~~ axle
γ = angle of slope of the ground.

Fig. 1.



Let C and C' be the centres respectively of the axle and wheel, A the point of contact between the axle and pipe-box, B the point of contact between the wheel and ground; also, let the direction of the power meet the vertical through the centre of the axle in E. The forces acting upon the axle are P, W, and the resistance of the pipe-box. P and W have a certain resultant; let it be R, and let the angle its direction makes with the vertical be θ. Supposing the axle to be in a state of equilibrium, the resistance opposed by the bearing of the pipe-box must be equal and opposite to R; and further, supposing the axle to be just on the point of motion, the direction of the resistance must make an angle ϕ with the normal to the point of contact. Hence, we have the angle $EAC = \phi$, and the following relations, viz.:—

$$P \cos \beta = R \sin \theta, \quad \ldots\ldots(1)$$

$$P \sin \beta + R \cos \theta = W. \quad \ldots\ldots(2)$$

The forces acting upon the wheel, are the pressure on the pipe-box, the weight of the wheel, and the resistance of the ground. Supposing the wheel to be in a state of equilibrium, the resultant of the first two must pass through B—the point of contact between the wheel and the ground. Calling the resultant R', and denoting the angle its direction makes with the vertical by θ', we have the following relations, viz.:—

$$R \sin \theta = R' \sin \theta', \quad \ldots\ldots(3)$$

$$R \cos \theta + W' = R' \cos \theta'. \quad \ldots\ldots(4)$$

Also,

$$\sin \theta = \sin \phi \cdot \frac{AC}{CE},$$

and

$$\frac{AC}{CE} = \frac{AC'}{C'D} = \frac{AC'}{C'B} \cdot \frac{C'B}{C'D} = \frac{AC'}{C'B} \cdot \frac{\sin \theta'}{\sin (\theta' - \gamma)};$$

therefore,

$$\sin \theta = \frac{AC'}{C'B} \cdot \frac{\sin \theta' \cdot \sin \phi}{\sin (\theta' - \gamma)}. \quad \ldots\ldots(5)$$

In order that the wheel may roll, it is only necessary that the direction of R' should fall to the left of the point B, instead of passing through it.

If the wheel meet an obstacle, as at B', the effect, when the wheel is on the point of surmounting it, is merely to change the point of contact from B to B', and increase the angle θ' by an angle BDB'.

Wheels in the service are classed according to the size of the pipe-box—viz., first (or siege), second (or field), third (or transport), and special. The scantling of the material for each particular part of a wheel is fixed for the class, the dimensions determined upon in each case being the results of experience.

Passing on now to consider the component parts of the wheel in detail, and commencing with the nave, we see, from what has been said about friction, that the more play there is allowed between the pipe-box and the axletree-arm (that is, the greater the difference of their radii),

the less will be the amount of the friction developed between them. But, in opposition to this, there is the consideration that, should there be any cross action of the pipe-box on the arm, it should be allowed as little room for action as possible. To this latter, practically, attention is mainly directed, and only sufficient play is given to ensure freedom in working. The length of the pipe-box must be such as to give the wheel proper stability upon its arm, and also to furnish, besides enough grease recess, sufficient frictional bearings to prevent too rapid wear. A hard alloy, technically known as "metal," is now used as the material for pipe-boxes in preference to cast-iron, on account of the less development of friction between it and the iron arm.

For the flanges of the naves of artillery wheels metal is also employed, but of a softer nature than that used for pipe-boxes. In the naves of wheels for transport service the flanges are of wrought-iron, as being lighter, for the same strength, than metal.

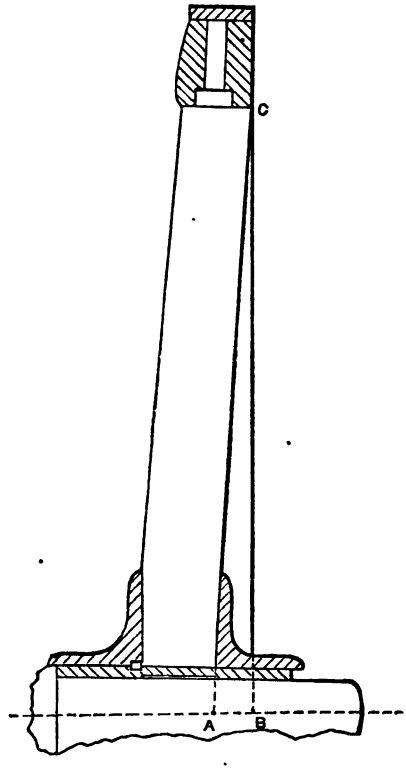
The position of the feet of the spokes in the nave is a point of importance. It must be such that, when the wheel is completed and on its carriage, the perpendicular from the centre of resistance, or centre of the bearing part of the tire on the ground, should pass within the cross-section of the lower or "working" spoke through the centre of pressure, in order that there may not be any cross action of the pipe-box on the axletree-arm. The centre of pressure is usually taken as represented by the central point of the axis of the pipe-box, though in reality it lies inside of this point.

A defect in the wood nave, as compared with the metal or Madras pattern nave, deserves here to be mentioned. In the former, from the mode of manufacture, more or less vacant space is always left between the feet of the spokes and the pipe-box; consequently, when the wood shrinks, the mortises enlarge, giving the spokes opportunity of entering further into them. When this is the case, as the wheel revolves and each spoke in succession becomes a working spoke, it will be pressed as far as it can go into the stock; while the spokes which for the time are upper, will be rather drawn out from the stock. Thus, as the wheel continuously rolls, the spokes will work in and out of the nave, and the wheel cannot last.

Spokes, for strength, are made of oak; and to ensure the proper direction of the fibre, are cleft from the tree. From the latter circumstance, they shew on their deeper sides that appearance of the fibre which is termed the "felt." The most severe stress to which spokes are subject, is from the lateral thrust brought to bear upon the nave when one wheel becomes lower than the other by dipping into a rut, &c. In order, therefore, to place them in a better position to resist this thrust, the wheel is "dished," or formed into a kind of dome; and just as the dome or arch is strong, from its form, to resist pressure upon the crown tending to crush it in, so is the wheel made strong by the dish to resist the lateral thrust tending to force the nave outwards. In fact, not only do the spokes, sustained by the tire, yield mutual support to each other, but the lateral thrust upon each becomes partly converted into a compressing strain, which the wood has better power to resist. The greater the dish, the stronger the wheel will be to resist the lateral

strain; but, for other reasons to be mentioned further on, no more dish should be given than necessary for the safety of the spokes. The amount of dish in a wheel is measured along its axis, from the point *A* (Fig. 2), where the prolongation of the face of the spoke meets that

Fig. 2.



axis, to the point *B*, where the perpendicular let fall from the extremity of the face at the bosom of the felloe meets the same axis. This in the O.P. field wheel of 5 ft. diameter is ~~3·375 ins. (measured close above the nave instead of along the axis it amounts to 2½ ins.~~, and hence is usually, though incorrectly, said to be ½ in. to 1 ft. In the N.P. field wheel, the dish has been reduced to 2 ins., and experiment has shown that it cannot be further reduced with safety to the spokes, except in some cases, where the dish of a low front wheel is made to suit the track of the hind wheel. The amount of dish in wheels not of 5 ft. diameter is proportional to that in the 5 ft. wheel (that is, ~~to 3·375 ins~~. if O.P., and to 2 ins. if N.P.), for the relative lengths from the axis to the bosom of the felloe.

Dishing a wheel carries with it some minor advantages—for instance, giving greater width between the wheels above the axletree

for the load; and one great disadvantage—namely, the bevelling of the sole of the wheel, which is brought about by the necessity, consequent upon the dish, of having to set the axletree-arm at an angle downwards. The bevelling makes the wheel conical in form, instead of cylindrical. Now a cone, we know, if set in motion on the level, will describe a circular path round its apex as centre; so the wheel, if set in motion and free, would describe a circular path round the point where the prolongation of its sole would meet the prolongation of its axis—or, in other words, where the latter would meet the ground. On the carriage, the wheel is compelled to move straight forward, in a path unnatural to it; and consequently, instead of rolling it partly slides, thereby, as it were, giving a frictional surface between the ground and the body moved, and tending to defeat the primary object of using wheels.

The dish of a wheel is measured practically by laying a straight-edge across the face of the wheel, just above the nave, and measuring the perpendicular distance from it to the foot of the spoke; which distance should agree with the same calculated by similar triangles, or with a similar measurement on a wheel of the same nature whose dish is known to be correct.

Ash, as a strong elastic wood, is used for felloes. The number of felloes in a wheel is fixed by the consideration that the length of each must not be so great as to necessitate the fibre of the wood being much cut across in shaping the felloe; and, at the same time, the fewer the felloes there are, the better for the strength of the wheel, as the junction between every two is a weak point. In the 5-ft. wheel six felloes is the approved number, each receiving two spokes. It is usual to cut felloes to a larger radius than that of the wheel for which they are intended, to prevent their extremities afterwards drooping; and from this circumstance a new wheel does not form a perfect circle.

With regard to the tire, which is of wrought-iron, its width to some extent depends upon the scantling of the felloes; but is mainly governed by the considerations that it ought to be at a maximum for passing over yielding ground, and at a minimum for lightness. With regard to the latter point, its thickness also should be at a minimum consistent with strength. Comparing the "ring" tire with the "streak" tire, we see that the former gives much better support to the other parts of the wheel; but in the case of a wooden nave, should the latter shrink, it cannot follow up the movement of the spokes mentioned before, which the streak tire (there being a small space between the ends of the streaks, and the bolts holding it being capable of yielding a little), to a certain extent can, and thus diminish the play of the spokes. The streak tire also admits of readier repair, should a felloe be damaged; but, on the other hand, on account of the number of bolts and rivets through the felloe, weakens the latter more than the ring tire, when one or at most two bolts are required.

The considerations which govern the height, or diameter, of a wheel are the following:—It should be at a maximum, in order to carry out as completely as possible the object and advantages in view of which wheels are used; but increase of diameter carries with it increase of weight and cost, and also decrease of stability, and entails, in the case of a gun-carriage wheel, greater inertia to recoil. There are cases, however—as with the

M.L.R. field guns and carriages—in which inertia to recoil in the wheels is a desideratum, providing their strength admits of their accepting it. Further, the height of the shafts and convenience of loading must be taken into consideration in determining the diameter of a wheel. In the field wheel, and other wheels for ordinary purposes, the height of 5 ft. has been adopted, as best fulfilling the above conditions; in other wheels the height is varied to suit special requirements.

With regard to the weight of a wheel, it should be at a minimum, provided the strength is sufficient, to increase the mobility and diminish (in the case of a gun-carriage) the inertia of recoil; but, as before said, there are cases in which it is advantageous to increase the inertia. It is further convenient, when circumstances admit of it, to have the weight not greater than two men can lift.

Wrought-iron is employed as the material for axletrees, on account of its strength and toughness. If for use with wheels having cast-iron pipe-boxes, the arms are steeled, to prevent too rapid wear.

The general dimensions of an axletree depend, naturally, upon the weight and nature of the load which it has to support. Its cross section is kept at a minimum, consistent with strength, for the sake of lightness, and also in the arms, in order that what friction is produced between them and the wheels may have as small a leverage in its favour as possible.

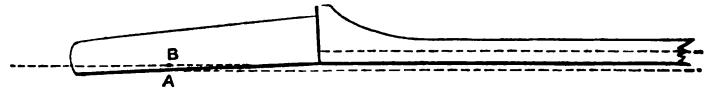
In axletrees bedded in wood, the body of the axle is made rectangular in cross section, that there may be better hold or union between the axle and the bed. In the later patterns of transport wagons, wood beds have been dispensed with, as inconvenient and superfluous. In these carriages the whole strain, whether vertical or horizontal, is applied close to the shoulder of the axletree, and the body within these straining points is relieved; hence a smaller section is admissible for the latter, and as it has no strain in any particular direction, as well as for convenience, its form is generally circular. A downward inclination or "hollow" is given to the axletree-arm, in order to bring the lower spoke vertical when it comes immediately under the arm, the wheels being on the level; otherwise, owing to the dish of the wheel, it would be in a bad position—in fact, the perpendicular from centre of resistance would not pass through centre of pressure in the pipe-box. When, under the above conditions, the working spoke is not brought quite vertical, but at an angle outwards to the vertical, the wheel is said to have a "strut," the amount of which is expressed in inches, and measured along the axis of the wheel from the point where the prolongation of the face of the spoke meets it, to the point where the vertical drawn from the extremity of the face at the bosom of the felloe meets the same axis.

Though, on the level, giving a strut to the wheel is slightly disadvantageous, on the whole a certain amount of strut is decidedly good, as assisting the wheel—or rather its lower or working spoke—under the most trying circumstances, when it dips into a rut, &c. Formerly, most wheels had more or less strut; for instance, the field wheel had about 1 in. At present, no strut is given in the N.P. field wheel, but ½ in. in the 5-ft. wheel for transport carriages, and to others for the same service in proportion.

It will be seen from the foregoing that the amount of hollow given depends entirely upon the dish of the wheel, together with the amount of strut it is desired to give.

The hollow is expressed in parts of an inch, and measured as the perpendicular distance from a point *A* (Fig. 3), in the under edge of the

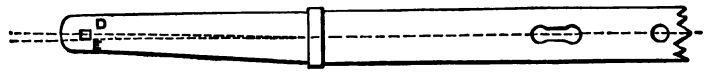
Fig. 3.



arm, distant from the shoulder the length of the pipe-box, to a point *B*, in a line drawn parallel to the axis of the body, and touching the lowest point of the base of the arm. This manner of reckoning the hollow, though convenient, is not strictly correct, as it takes into account the amount of cone of the arm. Practically, the hollow may be measured with sufficient exactness by stretching a string from one linchpin-hole to the other, on the under side, and measuring the distance from the string to the base of the arm. The amount of the hollow is always such as to point the arm downwards, notwithstanding its conical form; which has the effect of relieving the washer and linchpin of the pressure which the nave would otherwise have against them, due to the tendency of the wheel to roll outwards.

In addition to the "hollow," an inclination to the front, or "lead," is given to the axletree-arm, in order to place the front part of the wheel, as in revolving it approaches the ground, more in the direction in which the wheel is intended to travel, and from which the hollow of the arm, as well as the dish of the wheel, make it to deviate. The lead thus causes the wheel to meet any obstacle which opposes it more directly, as regards the spoke on which the stress due to the resistance of the obstacle happens mainly to fall; in fact, it does for that spoke what the hollow does for the lower spoke. Strictly speaking, the amount of the lead should be proportional to the dish of the wheel; being, however, small, it has been empirically fixed at $\frac{1}{16}$ in., and is measured in the same manner as the hollow (Fig. 4).

Fig. 4.



It will be seen from the preceding remarks upon the wheel and axletree, that in planning the former, after its general dimensions have been fixed, the amount of "dish" and of "strut" have to be determined; from which follow the amount of "hollow" of the axletree-arm, and then from the latter the amount of bevel of the sole of the wheel.

TRACTION.

(No. I)

BY

MAJOR W. KEMMIS, R.A.

REPRINTED FROM

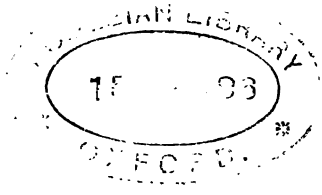
"PROCEEDINGS, ROYAL ARTILLERY INSTITUTION," No. 3, Vol. IX.

WOOLWICH:

PRINTED AT THE ROYAL ARTILLERY INSTITUTION.

M.DCCC.LXXV.

2316.d.13 (5)



TRACTION.

BY

MAJOR W. KEMMIS, R.A.

In a previous paper, "Principles of Construction of Wheels and Axles," ("Proceedings, R.A. Institution," Vol. VIII. p. 369), the relations between the forces which act upon the wheel and axle when upon the point of motion have been stated as follows:—

W = half weight of axle and load,
P = traction, or moving power, its direction making an angle β with the horizontal,
R = resultant of P and W, its direction making an angle θ with the vertical,
W' = weight of the wheel,
R' = resultant of R and W', its direction making an angle θ' with the vertical,
ϕ = limiting angle of resistance between the pipe-box and axletree-arm,
γ = angle of slope of the ground,
AC' = radius of the pipe-box,
BC' = radius of the wheel.

Then

$$P \cdot \cos \beta = R \cdot \sin \theta, \quad \ldots\ldots(1)$$

$$P \cdot \sin \beta + R \cdot \cos \theta = W, \quad \ldots\ldots(2)$$

$$R \cdot \sin \theta = R' \cdot \sin \theta', \quad \ldots\ldots(3)$$

$$R \cdot \cos \theta + W' = R' \cdot \cos \theta', \quad \ldots\ldots(4)$$

$$\sin \theta = \frac{AC'}{C'B} \cdot \frac{\sin \theta' \cdot \sin \phi}{\sin (\theta' - \gamma)}. \quad \ldots\ldots(5)$$

Proceeding from these equations to obtain the value of P; by combining (1) with (2),

$$\sin \theta = \frac{P \cdot \cos \beta}{\sqrt{W^2 + P^2 - 2P \cdot W \cdot \sin \beta}}, \quad \ldots\ldots(1')$$

and (3) with (4),

$$\frac{\cos\theta'}{\sin\theta'} = \frac{R\,.\cos\theta + W'}{R\,.\sin\theta}, \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2')$$

while, from (5),

$$\frac{\cos\theta'}{\sin\theta'} = \frac{C'B\,.\sin\theta\,.\cos\gamma - AC'\,.\sin\phi}{C'B\,.\sin\theta\,.\sin\gamma} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3')$$

Combining, then, equation (2') with (3'),

$$\frac{R\,.\cos\theta + W'}{R\,.\sin\theta} = \frac{C'B\,.\sin\theta\,.\cos\gamma - AC'\,.\sin\phi}{C'B\,.\sin\theta\,.\sin\gamma};$$

and substituting in this for $R\,.\cos\theta$ its value in (2), for $R\,.\sin\theta$ its value in (1), and for $\sin\theta$ its value in (1'),

$$\frac{W - P\,.\sin\beta + W'}{P\,.\cos\beta} = \frac{\cos\gamma}{\sin\gamma} - \frac{AC'}{C'B}\,.\,\frac{\sin\phi}{\sin\gamma}\,.\,\frac{\sqrt{W^2 + P^2 - 2P\,.\,W\,.\sin\beta}}{P\,.\cos\beta};$$

from which

$$\begin{aligned} &P^2\{C'B^2\,.\cos^2(\beta-\gamma) - AC'^2\,.\sin^2\phi\} \\ &\quad + 2P\{AC'^2\,.\sin^2\phi\,.\sin\beta\,.\,W - C'B^2\,.\cos(\beta-\gamma)\sin\gamma\,(W+W')\} \\ &\quad = AC'^2\,.\sin^2\phi\,.\,W^2 - C'B^2\,.\sin^2\gamma\,(W+W')^2, \end{aligned}$$

and therefore

$$\begin{aligned} P = \frac{AC'\,.\sin\phi}{C'B^2\,.\cos^2(\beta-\gamma) - AC'^2\,.\sin^2\phi}\,.\,&\sqrt{C'B^2\{(W+W')^2\sin^2\gamma + W^2\,.\cos^2(\beta-\gamma) - \\ &2W(W+W')\cos(\beta-\gamma)\sin\gamma\,.\sin\beta\} - AC'^2\,.\sin^2\phi\,.\cos^2\beta\,.\,W^2} \\ &+ \frac{C'B^2\,.\cos(\beta-\gamma)\sin\gamma\,(W+W') - AC'^2\,.\sin^2\phi\,.\sin\beta\,.\,W}{C'B^2\,.\cos^2(\beta-\gamma) - AC'^2\,.\sin^2\phi}; \end{aligned}$$

or

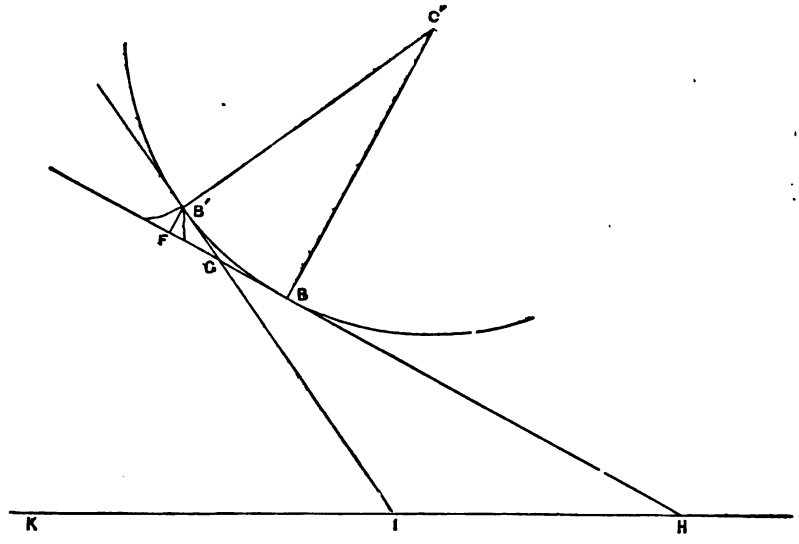
$$\begin{aligned} P = \frac{AC'\,.\sin\phi}{C'B^2\,.\cos^2(\beta-\gamma) - AC'^2\,.\sin^2\phi}\,.\,&\sqrt{C'B^2\{\cos^2\beta\,.\,W^2 + \sin^2\gamma\,.\,W'^2 + \\ &(\sin^2\gamma + \cos^2\beta - \cos^2(\beta-\gamma)\,WW'\} - AC'^2\,.\sin^2\phi\,.\cos^2\beta\,.\,W^2} \\ &+ \frac{C'B^2\,.\cos(\beta-\gamma)\sin\gamma\,(W+W') - AC'^2\,.\sin^2\phi\,.\sin\beta\,.\,W}{C'B^2\,.\cos^2(\beta-\gamma) - AC'^2\,.\sin^2\phi}; \end{aligned}$$

which, if the co-efficient of friction or $\tan\phi = \mu$, becomes

$$\begin{aligned} P = \frac{AC'\,.\,\mu}{C'B^2(1+\mu^2)\cos^2(\beta-\gamma) - AC'^2\,.\,\mu^2}\,.\,&\sqrt{C'B^2(1+\mu^2)\{\cos^2\beta\,.\,W^2 + \sin^2\gamma\,.\,W'^2 + \\ &(\sin^2\gamma + \cos^2\beta - \cos^2(\beta-\gamma)WW'\} - AC'^2\,.\,\mu^2\,.\cos^2\beta\,.\,W^2} \\ &+ \frac{C'B^2\,(1+\mu^2)\cos(\beta-\gamma)\sin\gamma\,(W+W') - AC'^2\,.\,\mu^2\,.\sin\beta\,.\,W}{C'B^2\,(1+\mu^2)\cos^2(\beta-\gamma) - AC'^2\,.\,\mu^2}. \qquad \ldots(A) \end{aligned}$$

If now the wheel meet an obstacle, the effect, when the wheel is on the point of surmounting it, is to change the point of contact with the ground from B to B'; or, in other words, to increase for the instant the slope of the ground by an angle equal to that subtended by the height of the obstacle at the point in which the tangent to the wheel, at the new point of contact, meets the line of the slope of the ground. Thus, in Fig. 1, the wheel meeting an obstacle whose height equals

Fig. 1.



$B'F$, is tantamount to the slope of the ground being increased by the angle $B'GF$, $B'I$ being drawn tangential to the wheel at B'; for

$$\angle GIK = \angle IGH\,(= B'GF) + \angle GHI;$$

or, denoting the angle due to the obstacle by ϵ, and the increased angle of the slope of the ground by γ',

$$\gamma' = \epsilon^* + \gamma,$$

and

$$P = \frac{AC' \cdot \mu}{C'B^2(1+\mu^2)\cos^2(\beta-\gamma') - AC'^2 \cdot \mu^2} \cdot \sqrt{C'B^2(1+\mu^2)\{\cos^2\beta \cdot W^2 + \sin^2\gamma' \cdot W'^2 + (\sin^2\gamma' + \cos^2\beta - \cos^2(\beta-\gamma')\, WW'\} - AC'^2 \cdot \mu^2 \cdot \cos^2\beta \cdot W^2}$$

$$+ \frac{C'B^2(1+\mu^2)\cos(\beta-\gamma')\sin\gamma'(W+W') - AC'^2 \cdot \mu^2 \cdot \sin\beta \cdot W}{C'B^2(1+\mu^2)\cos^2(\beta-\gamma')^2 - AC'^2 \cdot \mu^2} \cdot \quad \ldots(B)$$

* In the case of the wheel moving down an incline and meeting an obstacle, ϵ is negative.

Let h = the height of the obstacle; then

$$\sin \epsilon \ (= \angle B'C'B) = \frac{\sqrt{2h \,.\, C'B - h^2}}{C'B}, \quad \ldots\ldots\ldots\ldots (C)$$

which determines the value of ϵ.

Every road, no matter how apparently good, has its imperfections—namely, in its want of perfect smoothness and hardness; and every wheel, no matter how apparently true, in the same manner, has its irregularities of form. These defects oppose the motion of the wheel—in fact, place an obstacle of more or less magnitude continually in its path tantamount to an incline of more or less slope; so that whether on the level or on sloping ground, there is always an angle ϵ to be taken into account.

Suppose the wheel to be on a level road, and the direction of the traction to be parallel to the ground, then in the equation for P the angle $\beta = o$, $\gamma = o$, and $\gamma' = \epsilon$; so that the equation becomes

$$P = \frac{AC' \,.\, \mu \sqrt{C'B^2 (1+\mu^2)(W^2 + \sin^2 \epsilon \,.\, W'^2 + 2 \sin^2 \epsilon \,.\, WW') - AC'^2 \,.\, \mu^2 \,.\, W^2}}{C'B^2 (1 + \mu^2) - AC'^2 \,.\, \mu^2}$$

$$+ \frac{C'B^2 (1 + \mu^2) \cos \epsilon \,.\, \sin \epsilon \,.\, (W + W')}{C'B^2 (1 + \mu^2) - AC'^2 \,.\, \mu^2}. \quad \ldots\ldots\ldots\ldots\ldots\ldots (D)$$

Imagine now, under the same circumstances, the road to be most favourable for traction (more so than ever practically met with), opposing but a very slight obstacle to the wheel—one of so small height as only sufficient to call into play the maximum resistance of friction between the pipe-box and the axletree-arm; then the equation approximates to

$$P = \frac{AC' \,.\, \mu \,.\, W}{\sqrt{C'B^2 (1+\mu^2) - AC'^2 \,.\, \mu^2}}. \quad \ldots\ldots\ldots\ldots\ldots\ldots (E)$$

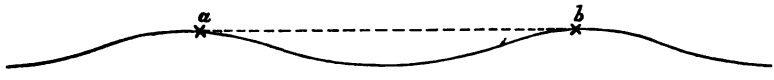
From which it appears that on a hard level road the traction or amount of power necessary to put a wheel in motion is directly proportional to the radius of the pipe-box, the co-efficient of friction between the pipe-box and axle, and the weight of and upon the axle, while it is approximately inversely proportional to the radius of the wheel.

It is evident that this equation (or any former one for P), though deduced from consideration of a single wheel, requires no modification to make it suitable for the traction of any two-wheeled carriage, or four-wheeled carriage with fore and hind wheels of equal height. It is simply necessary to give W its proper value—namely, the weight of the carriage body and its load. If, however, it is required to ascertain the traction of a "lock-under" wagon, in which the fore wheels are of smaller diameter than the hind, it is obvious that the traction of the fore and hind carriage must be calculated separately, W being given in each case an appropriate value—namely, that proportion of the weight of the carriage body and load borne by the particular pair of wheels; the total traction being then taken as the sum of that of the parts.

Applying, in this manner, the formula for P to wagons, one or two inferences may be drawn from it.

In the first place, it is apparent that the distance between the axles never enters the question; that is to say, their distance apart does not affect the traction. (If it was granted that the surface of the road upon which the wagon was destined to travel was, in its length, uniformly wavy—as in Fig. 2—the distance apart of the axles might be

Fig. 2.



suited to the particular length of wave, but to no other. Thus, it would obviously be bad to have the distance apart of the axles the same as the distance, *ab*, from one wave to the other, because in that case both the fore and hind carriage wheels would be ascending at the same time, causing a maximum traction, and at the next instant both descending, causing a minimum. Manifestly, in this case, the best length between the axles would be $\frac{1}{2}ab$, so that one pair of wheels would always be descending, and therefore their traction decreasing, when the other pair were ascending, and therefore their traction increasing.)

In the next, that the distribution of the weight over the axles should, in a "lock-under" wagon, be as the radii of the wheels. Practically, rather less than this should be thrown upon the fore-wheels, because the obstacles to their traction are usually greater than to that of the hind wheels, due to their first meeting the obstacles, and, in passing over them, reducing their height for the hind. In an "equirotal" wagon, the same reason for throwing rather less weight on the fore than on the hind wheels holds equally good: setting, however, this point aside, it appears from the formula that in such a wagon it is a matter of indifference how the load is distributed over the axles; and this would practically be true was it not for the yielding nature of most roads permitting the weight to sink the wheels into them, which must occur to a greater extent if the weight is thrown mainly upon one pair of wheels—*i.e.* upon two points of support, instead of distributed more equally over four.

Equation (*A*) may be made more simple by supposing the direction of the traction to be parallel to the ground: thus making $\beta = \gamma$,

$$P = \frac{AC' . \mu \sqrt{C'B^2(1+\mu^2)(\cos^2\gamma . W^2 + \sin^2\gamma . W'^2) - AC'^2 . \mu^2 . \cos^2\gamma . W^2}}{C'B^2(1+\mu^2) - AC'^2 . \mu^2}$$

$$+ \frac{\sin\gamma \{C'B^2(1+\mu^2)(W+W') - AC'^2 . \mu^2 . W\}}{C'B^2(1+\mu^2) - AC'^2 . \mu^2} . \quad \ldots\ldots\ldots\ldots\ldots\ldots (F)$$

The resistance which an obstacle of even small height offers to traction deserves to be noticed. It is measured, as already shewn, by the increase which for the instant it adds to the slope of the ground. Suppose, for illustration, a 5-ft. wheel to meet an obstacle $\frac{1}{16}$ in. in height. By equation (*C*),

$$\sin\epsilon = \cdot 0645,$$

$$\text{and } \therefore \epsilon = 3^\circ\ 45' \text{ (very nearly).}$$

If the obstacle be $\frac{1}{8}$ in. in height, $\epsilon = 5^\circ\ 14'$; if $\frac{1}{4}$ in., $\epsilon = 7^\circ\ 24'$; if $\frac{1}{2}$ in., $\epsilon = 10^\circ\ 28'$; and if 1 in., $\epsilon = 14^\circ\ 50'$.

Thus, to make a carriage which has the ordinary field wheel pass an unyielding obstacle of only 1 in. in height, the horses have for the instant to put forth as much power as would be required to move the same carriage on an incline of about 15°.

The smaller the carriage wheel, the worse it is for passing over an obstacle. Thus, suppose it be a wheel 3 ft. 4 ins. instead of 5 ft. in diameter which meets the obstacle $\frac{1}{2}$ in. in height, and ϵ becomes $12^\circ\ 50'$ instead of $10^\circ\ 28'$, while in the case of the obstacle 1 in. in height it becomes $18^\circ\ 12'$ instead of $14^\circ\ 50'$. From this, setting aside the fact that the traction on the level is inversely proportional to the radius of the wheel, the evil of giving a carriage a low front wheel is evident.

In the 9-pr. M.L.R. gun-carriage and limber, Mark II. (packed),

$$AC' = 1{\cdot}38 \text{ ins.},$$
$$C'B = 30 \text{ ins.},$$
$$W = 3032 \text{ lbs.},$$
$$W' = 920 \text{ lbs.}$$

Taking $\mu = {\cdot}01$, and inserting these values in equation (E), or—what is sufficiently near for all practical purposes—in the modification of it, $P = \frac{AC' \cdot \mu \cdot W}{C'B}$, the traction of the carriage on the level in a direction parallel to the ground is found to be equal to 1·426 lbs.

This, in the usual direction of the traces—namely, at an angle of $6\frac{1}{2}^\circ$ with the horizontal—amounts to 1·448 lbs. Now, as a matter of fact, far greater power than this is required to move the carriage on even the best road, and the apparent discrepancy is simply due to the imperfections of the road and the wheels, which oppose a constant resistance to the motion of the latter; in fact—as mentioned in a former place—whether the carriage is on the level or on an incline, there is always an angle ϵ, depending in amount upon the nature of the road, to be taken into account.

It is in consequence of this that the inclination of $6\frac{1}{2}^\circ$ is given to the traces; and giving this to the line of traction is as much as saying that the average obstacle to the motion of the carriage on the usual nature of road it has to travel over (whether level or inclined), is one whose height will give an angle $\epsilon = 6\frac{1}{2}^\circ$.

In this view, if in equation (B) γ be made $= o$, and $\gamma' = \epsilon\ (= \beta)$, the true traction, under average circumstances on the level, will more nearly be arrived at. Thus

$$P = \frac{AC' \cdot \mu \sqrt{C'B^2(1+\mu^2)(\cos^2\epsilon \cdot W^2 + \sin^2\epsilon \cdot W'^2) - AC'^2 \cdot \mu^2 \cdot \cos^2\epsilon \cdot W^2}}{CB^2(1+\mu^2) - AC'^2 \cdot \mu^2}$$
$$+ \frac{CB^2 \cdot (1+\mu^2)\sin\epsilon(W+W') - AC'^2 \cdot \mu^2 \cdot \sin\epsilon \cdot W}{CB^2(1+\mu^2) - AC'^2 \cdot \mu^2},$$

which, for all practical purposes, may be modified to

$$P = \frac{AC'\mu \,.\, W.\cos\epsilon}{C'B} + (W + W')\sin\epsilon;$$

$$\therefore\ (\epsilon = 6\tfrac{1}{2}^\circ)\ P = \frac{41{\cdot}5696}{30} + 447{\cdot}3664$$

$$= 448{\cdot}7187, \text{ or with a team of 6 horses } 74{\cdot}7864 \text{ lbs. per horse.}$$

In the 16-pr. M.L.R. gun-carriage with limber, Mark II. (packed), $W = 3665$ lbs. and $W' = 1000$ lbs.; therefore, under the same circumstances,

$$P = \frac{50{\cdot}8482}{30} + 528{\cdot}0780$$

$$= 529{\cdot}7729 \text{ lbs., or with a team of 6 horses } 88{\cdot}2955 \text{ lbs. per horse: and with a team of 8 horses } 66{\cdot}2216 \text{ lbs. per horse.}$$

That is, the traction of the 16-pr. gun-carriage is to that of the 9-pr. as 1·18 : 1.

In the foregoing remarks the traction has been considered as applied at the axle, its particular point of application there being determined by the equation $CE = \frac{\sin\phi}{\sin\theta} \,.\, AC$ (see "Proceedings, R.A. Institution," Vol. VIII. p. 371), where CE is the vertical distance of the point below the centre of the axle, and AC the radius of the latter, while $\sin\theta = \frac{P\cos\beta}{\sqrt{W^2 + P^2 - 2PW\,.\,\sin\beta}}$ by (1′).

In practice, the traction is usually from the splinter-bar; a consequence of which is that in a wagon fitted with frame shafts hinged to the bar a strain is thrown upon the connecting parts of the fore and hind carriages, and in a cart or limbered wagon with fixed shafts a pressure upon the shaft horse's back equal to $P \,.\, \frac{a}{b}$, where a and b are perpendiculars let fall from the point of application of P, when considered as applied at the axle, respectively upon the direction of P applied at the splinter bar and upon the vertical drawn through the positions of the tugs on the shafts.

In the 9 and 16-pr. limber, Mark II., neglecting the small distance CE—that is, taking the centre of the section of the axle-arm, at the shoulder, as the point of application of P when applied at the axle—the distance $a = 8\frac{3}{4}$ ins. and $b = 7$ ft. 8 ins.; therefore $\frac{a}{b} = {\cdot}095$. Or, to take particular cases, if $P = 448{\cdot}7187$ lbs.—as in the example of the 9-pr. gun-carriage above given—the pressure on the horse, due to the traction being from the splinter-bar, equals 42·628 lbs.;* while if $P = 529{\cdot}7729$ lbs.—as in the example of the 16-pr. gun-carriage—the pressure on the horse from the same cause equals 50·328 lbs.*

WOOLWICH,
December, 1874.

* In addition to the constant pressure of about 60 lbs. due to his bearing a portion of the weight of the carriage.

TRACTION.

[No. II.]

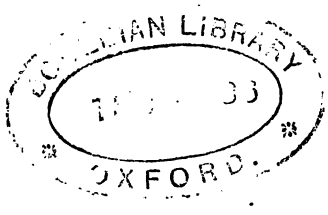
BY

MAJOR W. KEMMIS, R.A.

REPRINTED FROM
"PROCEEDINGS, ROYAL ARTILLERY INSTITUTION," No. 8, VOL. IX.

WOOLWICH:
PRINTED AT THE ROYAL ARTILLERY INSTITUTION.
M.DCCC.LXXVI.

2316.d.13 (6)


BODLEIAN LIBRARY
OXFORD

TRACTION.

[No. II.]

BY

MAJOR W. KEMMIS, R.A.

In order to calculate the load which a horse may fairly be called upon to move, it is necessary, first, to lay down the average speed at which he is required to travel, and the average nature of ground over which he has to pass.

As pointed out in a previous paper on Traction,* the *average* nature of ground which field artillery has to manœuvre upon may be considered to be that which opposes an average obstacle or resistance to rolling whose height is equivalent to a slope of $6\frac{1}{2}°$.

The *average* pace of manœuvre is the "trot, regulated with reference to the slowest horse,"† which may be taken as meaning a speed of 7 miles an hour for horse artillery and 6 miles an hour for field batteries.

A good draught horse, it is considered, moving at the former speed, can exert an *average*‡ tractive force of 70 lbs., and at the latter a force of 82 lbs.—the duration of labour being from 4 to 5 hours.§

The tractive power of a team is not directly proportional to the number of horses in it; in fact, it has been asserted that no more than six horses can usefully be employed in a team, if much speed is required.

Assuming, however, that the full power of the individual units is obtainable from a team of six horses, when well trained and well

* "Proceedings, R.A. Institution," Vol. IX. p. 138.

† "Manual of Field Artillery Exercises," 1875.

‡ "He adapts himself admirably to his work, increasing or diminishing his efforts according to the variations of draught—resting himself, as it were, and acquiring vigour where his utmost strength is not called for; and thus becomes enabled to make exertions far beyond his *average* strength where any obstruction is to be overcome."—Youat on the Horse.

§ Rankine, in his "Manual of Civil Engineering," gives a tractive force of 64 lbs. for a speed of $7\frac{1}{2}$ miles per hour, and 96 lbs. for 5 miles per hour, in each case working 4 hours a day.

Tredgold, in his work on Railways, gives 83 lbs. for a speed of 4 miles per hour and 62·5 lbs. for 5 miles per hour, in each case the duration of labor being 6 hours; and states that if the hours of labor be lessened, the velocity may be raised much higher.

Youat concludes that when 6 or 8 miles per hour is required, the day's work should be 5 or 6 hours and the draught 80 to 100 lbs.

driven, we have the total tractive force of a gun-team for horse artillery as $70 \times 6 = 420$ lbs.

For a gun-team of six horses for a field battery, we have $82 \times 6 = 492$ lbs., and for a gun-team of eight for the same (making a deduction of 25 per cent. for the additional pair of horses) $82 \times 8 - 41 = 615$ lbs.

The relation between the tractive force and the load, on level ground, is given by the equation*

$$P = \frac{r \cdot \mu \cdot W \cdot \cos \epsilon}{R} + (W + W') \sin \epsilon, \quad \ldots\ldots(1)$$

$$\text{or } W = \frac{R\,(P - W' \sin \epsilon)}{r \cdot \mu \cdot \cos \epsilon + R \cdot \sin \epsilon}; \quad \ldots\ldots(2)$$

where P = tractive force in lbs., in the direction of the traces,
W = weight of carriage body and load in lbs.,
W' = weight of wheels,
$r\ (= AC'^*)$ = mean radius of axle-arm in inches,
$R\ (= C'B^*)$ = mean radius of wheel in inches,
μ = coefficient of friction between wheel and axle,
ϵ = angle of slope due to height of obstacle.

In field artillery carriages, $W' = 1015$ lbs., $r = 1{\cdot}38''$, $R = 29{\cdot}937''$, while μ may be taken as ·01; and for ground opposing an average resistance to rolling, as already stated, $\epsilon = 6\frac{1}{2}°$.

Inserting the above values, and making $P = 420$ in equation (2), we get the total load, or weight of carriage complete with its load proper, which a gun-team of six horses should, for horse artillery, be required to draw, thus:—

$$W = \frac{29{\cdot}937\ (420 - 1015 \times {\cdot}1132)}{1{\cdot}38 \times {\cdot}01 \times {\cdot}9935 + 29{\cdot}937 \times {\cdot}1132}$$
$$= 2693 \text{ lbs.},$$
$$\text{and } W + W' = 3708 \text{ lbs.}$$
$$= 33 \text{ cwt. } 0 \text{ qrs. } 12 \text{ lbs., total load.}$$

In the same manner, making $P = 492$, we find for a gun-team of six horses for a field battery,

$$W = 3328 \text{ lbs.},$$
$$\text{and } W + W' = 4343 \text{ lbs.}$$
$$= 38 \text{ cwt. } 3 \text{ qrs. } 3 \text{ lbs., total load;}$$

and making $P = 615$ for a team of eight horses for the same,

$$W = 4414 \text{ lbs.},$$
$$\text{and } W + W' = 5429 \text{ lbs.}$$
$$= 48 \text{ cwt. } 1 \text{ qr. } 25 \text{ lbs., total load.}$$

* See "Traction," "Proceedings, R.A. Institution," Vol. IX. p. 138.

From the foregoing, it appears that the load which each horse should be required to draw is

618·0 lbs. for horse artillery,
723·8 lbs. for light field batteries,
678·6 lbs.* for heavy field batteries.

This Decker† lays down as

500·0 lbs. for horse artillery,
650·0 lbs. for foot artillery;

adding that these are less than they actually would be on service; while Migout and Bergery, in their "Essay on Gun-carriages," give the following as the weight which each horse can draw under all circumstances of war:—

743·2 lbs. for light field batteries,
878·4 lbs. for field parks.

The ratio‡ of the tractive force to the total load, calculated by equation (2), or $\frac{P}{W+W'}$, averages $\frac{1}{8{\cdot}74} = {\cdot}11441 =$ the tangent of an angle of 6° 32′, nearly; and thus is in agreement with the statement in the "Mathematical Course" that "the tangent of the inclination of the traces should equal the ratio of the traction to the load"—the angle of inclination of the traces being 6° 30′, upon which, as mentioned in the former paper, the average resistance to rolling is based.

To compare, now, the load calculated that each gun-team should draw with that which it actually has to draw, we have—

	cwts.	qrs.	lbs.	
Horse artillery ...	37	1	10	actual total load,§
	33	0	12	calculated "
	4	0	26	difference.
Light field battery,	42	0	24	actual total load,‖
	38	3	3	calculated "
	3	1	21	difference.
Heavy field battery,	50	1	9	actual total load,¶
	48	1	25	calculated "
	1	3	12	difference.

* Less than in the case of light batteries, on account of the loss assumed for the larger number of horses driven together.

† "Principles and Practice of Modern Artillery," Lieut.-Colonel Owen, R.A.

‡ This ratio has been variously estimated. Rankine gives it as $\frac{1}{15}$ on gravel road and $\frac{1}{7}$ on soft, sandy, and gravelly ground; Youat as $\frac{1}{25}$ on road in good repair; while Migout and Bergery state that in 1825, at Metz, it was found to be $\frac{1}{25}$ over fine turf and $\frac{1}{10}$ over recently ploughed and hoed ground.

§ With 6 cwt. gun and two gunners mounted (at 13 stone each).

‖ With 6 cwt. gun and five gunners mounted.

¶ With 12 cwt. gun and five gunners mounted.

Or, per horse,

	lbs.	
Horse artillery ...	697·0	actual load,
	618·0	calculated load,
	79·0	difference.
Light field battery,	788·0	actual load,
	724·8	calculated load,
	65·2	difference.
Heavy field battery,	704·6	actual load,
	678·6	calculated load,
	26·0	difference.

The tractive force which each horse has to put forth to move the above actual loads is, as calculated by equation,

	lbs.
Horse artillery	79·14
Light field battery	89·45
Heavy field battery	85·33*

while the force which it is considered each should be called upon to exert, as already given, is

	lbs.
Horse artillery	70·00
Field batteries	82·00

It therefore appears that the gun-teams of horse artillery and light field batteries are considerably overweighted, those of heavy field batteries (of eight horses) not much so; and it is to be remembered that the calculated loads are based upon the supposition that the horses are in fair condition—"reduction of rations, occasional failure of food, and bivouacking often producing great diminution of power."†

Comparing now the light and heavy field battery teams, we find that the heavy battery is more mobile than the light; each horse in the team of the former having to make less exertion than in the team of the latter! In fact, the light field battery, as existing, does not seem, so to speak, an advantageous arrangement; for while the gun carried is but the same as in the case of horse artillery, the gun-team, of six horses, is overweighted, and if increased to eight would be just as much underweighted, and would become more mobile even than horse artillery—which is unnecessary. It would therefore seem better to abolish the light field battery and employ the heavy only, in which each horse is approximately but duly weighted, and yet the team has behind it the heaviest gun; or, if necessary to retain the light field battery, to increase the gun-team to eight horses, and at the same time to increase the weight (*i.e.*, the power also) of the gun carried—

* Allowing, as before, 25 per cent. loss on the leading pair of horses.

† No deduction has been made for any weight on their backs. Against this may be set the assistance which they may get from the momentum of the carriage in motion.

making the gun, total load, and tractive force required per horse a medium, as they should be, between those of horse artillery and heavy field batteries.

On the peace establishment the heavy field battery gun-team consists of but six horses; in which case we have

cwts.	qrs.	lbs.	
50	1	9	actual load,
38	3	3	calculated load,
11	2	6	difference;

and the actual tractive force 106·70 lbs. per horse, instead of 82 lbs., as it should be.

In teams for siege artillery carriages, the pace being the walk, it is usual to employ twelve horses, four abreast.

At the walk, it is considered that a good draught horse can exert a tractive force of 120 lbs.; therefore, deducting 25 per cent. loss for the four leading horses on account of the large number in the team, we have the total tractive force of the latter as $120 \times 12 - 120 = 1320$ lbs. From which, assuming the same average resistance to rolling as in the case of field carriages, or making $\epsilon = 6\frac{1}{2}°$, we find

$$W + W' = 108\frac{3}{4} \text{ cwts. approximately, total load.}$$

This gives 969 lbs. load per horse, which Decker lays down for siege artillery should be 750 lbs., and Migout and Bergery 1013·5 lbs.

The actual weight of a 64-pr. M.L.R. siege carriage and limber, packed, is 115 cwts. (about)—no ammunition carried—and of a 40-pr. M.L.R. carriage and limber, packed, 88½ cwts.—18 rounds of ammunition included—which gives for the former a load per horse of 1073 lbs. and tractive force of 132 lbs., and for the latter a load of 826 lbs. and force of 104 lbs.

From this, and considering also that the average resistance to rolling of the ground might fairly for a siege train be taken as greater than for field artillery, it seems reasonable to conclude that the 64-pr. is too heavy a gun to be mounted on a travelling carriage, unless exceptional circumstances render it desirable. If mounted on a standing carriage, the weight of gun, carriage, and platform wagon to transport both (together) would be about 100 cwts., and if mounted on a sliding carriage upon a traversing platform, fitted with transporting arrangement, the weight complete would be about 98 cwts. The latter arrangement could be made suitable for any height of parapet, and would have the further advantage that the gun would be brought into position mounted ready for use—no shifting from one carriage to another, or even changing from one set of trunnion-holes to another, being required.

Wagon versus Limbers.

It is advocated by some that three limbers, drawn by two horses each, might with advantage be substituted for the present ammunition

wagon with six horses—which is set down as a clumsy antiquated affair.*

At first sight, no doubt, such a change appears to have something of advantage in it, as in action the supply of ammunition to the gun, possible to some extent only now, could always be kept up by simply changing the gun-limber for another—though this would hardly seem to meet the views set forth in the "Field Artillery Exercise," where changing the limber to renew the supply of ammunition is laid down as exceptional, the ordinary method enjoined being to shift the ammunition from the full boxes of the wagon or its limber to the empty ones of the gun-limber.

Examining, however, the question in detail, we find the balance of advantage much in favour of the wagon, thus:—

The weight upon the shaft horse, in the wagon 60 lbs., becomes in the limber without a hind carriage 96 lbs., which weight each of three out of six horses, instead of but one, would be oppressed by; the same three horses, instead of but one, having also to bear the constant jerks communicated from the shafts—which, felt to some extent in a limbered wagon, without springs and with fixed shafts, are experienced in the highest degree in a two-wheeled carriage without springs.

Again, with regard to load and motive power, we have the total weight of a wagon (9-pr.) packed equal to 40 cwts. 0 qrs. 2 lbs., while that of three limbers (9-pr.) is 3 (15 cwts. 3 qrs. 4 lbs.) = 47 cwts. 1 qr. 12 lbs., which—the number of rounds of ammunition carried being the same in both cases—gives 7 cwts. 1 qr. 10 lbs. of additional and perfectly useless load. In other words, while in the wagon the load per horse is 747 lbs. and the tractive force required 87 lbs., for each limber these would be respectively 885·5 lbs. and 100 lbs.

Lastly, the number of carriages of a battery would be increased by 12, and the extent of the battery in column of route by 36 yds.†

JULY, 1876.

* The wagon can only be said to be out of place when issued to a battery on peace establishment. Would it not be better to place all wagons of horse and field artillery in reserve during peace, and in lieu—from the saving—keep up additional batteries of guns only?

† And query, where would the spare wheels and shafts be carried?

RESULTS OF EXPERIMENTS

MADE IN THE

ROYAL CARRIAGE DEPARTMENT,

(*in May and September*, 1876),

TO TEST THE RELATIVE STRENGTH OF DIFFERENT FORMS OF BRACKETS AND AXLETREES FOR FIELD GUN-CARRIAGES.

COMMUNICATED BY

MAJOR W. KEMMIS, R.A.

REPRINTED FROM

"PROCEEDINGS, ROYAL ARTILLERY INSTITUTION," No. 9, Vol. IX.

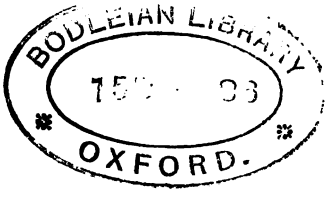
WOOLWICH:

PRINTED AT THE ROYAL ARTILLERY INSTITUTION.

M.DCCC.LXXVII.

D 2316 . 7 d. 13. (4)

21 . X . 16


BODLEIAN LIBRARY
OXFORD

RESULTS OF EXPERIMENTS

MADE IN THE

ROYAL CARRIAGE DEPARTMENT,

(*in May and September*, 1876),

TO TEST THE RELATIVE STRENGTH OF DIFFERENT FORMS OF BRACKETS AND AXLETREES FOR FIELD GUN-CARRIAGES.

COMMUNICATED BY

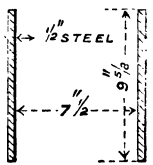
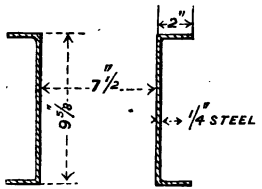
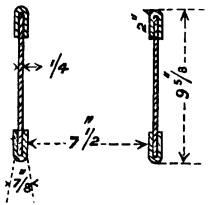
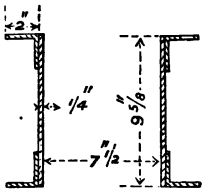
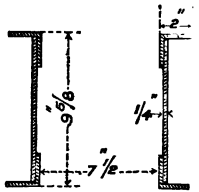
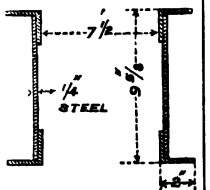
MAJOR W. KEMMIS, R.A.

I.—Brackets.

The specimens of brackets experimented upon were, approximately, of the same weight and dimensions; each consisted of two sides, of equal depth from end to end, 5′ 0″ long, connected by three collar bolts.

To test each specimen, it was supported with the sides vertical, their upper and under edges horizontal, upon two cast-iron blocks, 4′ 0″ apart; in which position a weight of 1134 lbs. was let fall, from a given height, upon a small wrought-iron block placed across the sides at the centre.

The particular section and weight of each bracket, together with the effect of the blows it received, are given in the following table:—

	A.	B.	C.	D.	E.	F.
	 Weight, 160 lbs.	 Weight, 117 lbs.	 Weight, 163 lbs.	 Weight, 168 lbs.	 Weight, 160 lbs.	 Weight, 170 lbs.
After 4 blows: one 2′ 0″ fall, three 1′ 6″ fall:—	ins.	ins.	ins.	ins.	ins.	ins.
Mean maximum vertical deflection	·350	·260	·237	·210	·125	·210
Mean maximum horizontal deflection.....	·255	·500	·365	·075	—	·155
Fracture	—	—	—	—	—	—
After 4 additional blows; 1′ 6″ fall:—						
Mean maximum vertical deflection	·650	·510	·365	·320	·355	·350
Mean maximum horizontal deflection.....	1·255	1·465	·875	·045	·100	·340
Fracture	—	—	—	—	—	—
After 2 additional blows; one 5′. one 6′ fall:—						
Mean maximum vertical deflection	1·665	1·210	1·850	1·075	1·235	1·175
Mean maximum horizontal deflection.....	6·350	1·755, and also in the opposite direction ·64.	3·000	·700	1·685	2·460
Fracture	—	—	—	Both plates fractured up 2¼″ from under edge, and at upper opened from angle-iron.	—	Upper angle-iron torn at centre, in direction of length.

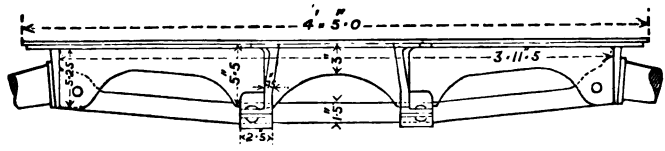
Specimen *A*, as might have been inferred from the disposition of the mass of the metal with regard to the neutral axis, shewed itself to be the weakest form, whether we regard vertical or horizontal strain. *B*, which is the form adopted in German field gun-carriages, stands next in weakness, being deficient in stiffness, and bending in all directions; it was, however, light in weight as compared with the other specimens. *C* shewed itself deficient in horizontal strength. *D*, *E*, and *F* proved the strongest forms, from the greater mass of metal in them remote from the neutral axes; *E* and *F* have the advantage over *D*, in the strain upon the rivets being relieved in them, and the liability of the plate tearing or cracking at the lower edge being reduced; the fracture of the upper angle-iron in *F* was due to it being compressed, locally, between the weight giving the blow and the hard steel plate beneath it—an action which could not take place in a gun-carriage.

II.—Axletrees.

The axletrees subjected to experiment were tested in the same manner as the specimens of brackets; the axletree arms were supported upon cast-iron blocks placed 4′ 1½″ apart, the upper surface of the axle-bed level, and the blow delivered by the falling weight (1134 lbs.) upon a wrought-iron block placed centrally across the top plate. The results obtained were as follows :—

	A.	B.	C.	D.	E.
	Weight, —	cwt. qr. lb. Weight, 2 0 4	cwt. qr. lb. Weight, 1 3 24	cwt. qr. lb. Weight, 1 3 25	cwt. qr. lb. Weight, 1 1 1½
After 6 blows; 1′ 6″ fall:— Maximum vertical deflection	Not tried.	ins. ·30	ins. ·35	ins. ·20	ins. ·12
Fracture		—	One angle-iron slightly fractured at centre of under edge.	One angle-iron slightly fractured at centre of under edge.	—
After 5 additional blows; 1′ 9″ fall:— Maximum vertical deflection		·75	·67	·35	·26
Fracture		Axle and angle-iron fractured at centre.	The other angle-iron similarly fractured.	The other angle-iron similarly fractured.	—
After 7 additional blows; one 1′ 9″ fall, six 2′ 0″ fall:— Maximum vertical deflection		—	1·72	·75	·50
Fracture		—	Fracture of angle-iron increased, and slight crack in axle.	Fracture of angle-irons very slightly increased.	—
After 6 additional blows; 2′ 0″ fall:— Maximum vertical deflection		—	1·90	·87	·54
Fracture		—	Axle broken through 6¼″ from shoulder.	Fracture of angle-irons very slightly increased.	—

The specimens, *C*, and *D*, were constructed by simply replacing the service straight axle, as in *B*, by a round bent axle, between angle-irons already drilled for the former, and fitting packing pieces between the top plate and the axle at the positions of the brackets. The correct form of this axle and bed, as proposed by Mr. Butter, Manager R.C.D., is shown in the figure, in which there could be no tendency of the angle-irons to crack at the lower edges. This construction is far stronger



than that of *B*, in that it is of deeper section, while the axle is not weakened by rivet holes, and is subjected to a purely tensile strain; it is also, if damaged, much more easily replaced, being secured by a few instead of many rivets, and being of small section, if broken, can be rewelded. The solid form, *E*, in steel, would, after slight damage, soon become unserviceable, and if broken could not be rewelded; it is also inconvenient for the attachment of axle seats, the necessary fittings for which would increase its weight considerably. In a comparison of strength to withstand statical pressure, made between the forms *A*, and *B*, it was found that while the breaking strain of the former was 22¼ tons, that of the latter was 54¾ tons.

ROYAL ARSENAL,

October 1876.

